U.S. DEPARTMENT OF COMMERCE
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PB-264 282

Design Parameters for the Land Application of Dairy Manure

Cornell Univ, Ithaca, N Y Dept of Agronomy

Prepared for

Environmental Research Lab, Athens, Ga.

Oct 76

PB 264 282

EPA-600/2-76-187
October 1976

Environmental Protection Technology Series

UNITED STATES · ENVIRONMENTAL PROTECTION AGENCY ·

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TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/2-76-187

2.

3. RECIPIENT'S ACCESSION NO.

4. TITLE AND SUBTITLE

Design Parameters for the Land Application of Dairy Manure

5. REPORT DATE

October 1976 (Issuing date)

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)

S. D. Klausner, P. J. Zwerman and D. R. Coote

8. PERFORMING ORGANIZATION REPORT NO.

9. PERFORMING ORGANIZATION NAME AND ADDRESS

Department of Agronomy
Cornell University
Ithaca, New York 14853

10. PROGRAM ELEMENT NO.

1BB039

11. CONTRACT/GRANT NO.

S 800767

12. SPONSORING AGENCY NAME AND ADDRESS

Environmental Research Laboratory - Athens, GA
Office of Research and Development
U.S. Environmental Protection Agency
Athens, Georgia 30601

13. TYPE OF REPORT AND PERIOD COVERED

Final

14. SPONSORING AGENCY CODE

EPA/600/01

15. SUPPLEMENTARY NOTES

Prepared in cooperation with the Cornell University Agricultural Experiment Station.

16. ABSTRACT

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A computer model dealing with the economic impact of control legislation was developed Modeling approaches to farm scale environmental problems are feasible if assumptions and simplifications do not influence the results too greatly, or in ways which are unpredictable.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
land economic analysis surface drainage subsurface drainage computer simulation yield	animal waste management manure fertilization guidelines	02/C/E

18. DISTRIBUTION STATEMENT Release unlimited	19. SECURITY CLASS *(This Report)* Unclassified	21. NO. OF PAGES 265
	20. SECURITY CLASS *(This page)* Unclassified	22. PRICE

EPA Form 2220-1 (9-73)

1a

U.S. GOVERNMENT PRINTING OFFICE: 1977-757-056/5468 Region No. 5-11

EPA-600/2-76-187
October 1976

DESIGN PARAMETERS FOR THE LAND APPLICATION OF DAIRY MANURE

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ATHENS, GEORGIA 30601

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ABSTRACT

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A computer model dealing with the economic impact of control legislation was developed. Modeling approaches to farm scale environmental problems are feasible if assumptions and simplifications do not influence the results too greatly, or in ways which are unpredictable.

This report was submitted in fulfillment of Grant Number S 800767 by Cornell University, Ithaca, New York under the partial sponsorship of the Environmental Protection Agency. Work was completed as of October, 1974.

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ACKNOWLEDGEMENTS

This research was supported by the Environmental Protection Agency under project number S 800767 and by the College of Agriculture and Life Sciences, Cornell University. The guidance of Mr. Lee Mulkey, Environmental Protection Agency, Athens, Georgia who served as the Project Officer and Dr. Raymond Loehr, Cornell University, who served as overall Project Coordinator is gratefully acknowledged.

Appreciation is expressed to Dr. P. J. Zwerman, Project Director, Cornell University.

The principal investigators associated with the project were S. D. Klausner (land application) and D. R. Coote (computer simulation).

The advice and help of Dr. D. Bouldin, G. W. Hergert, and H. T. Greweling and the support of Dr. M. J. Wright, Chairman, Department of Agronomy are gratefully acknowledged. Technical assistance was provided by D. F. Ellis, R. Jones, D. Decker and E. Callinan.

The patience and skill of A. Schoneman and S. Gray in typing this report are sincerely appreciated.

SECTION I

CONCLUSIONS

1. The soil system in itself appeared to be an excellent disposal medium for dairy manure. The retaining efficiencies of nitrogen and phosphorus ranged from 89 to 99% for the imposed treatments for both nutrients.

2. Throughout the course of the experiment, the lowest rate of application (35 t/ha) yielded the lesser annual discharge of nitrogen and phosphorus in surface runoff. The highest rate of application (200 t/ha) resulted in nearly twice the discharge of nitrogen in comparison to the lowest rate during both 1972 and 1973.

   Surface runoff discharges of inorganic nitrogen and total soluble phosphorus showed a marked difference, for all treatments, between 1972 and 1973. The average increase in 1972 over 1973 was 750% and 340% for nitrogen and phosphorus, respectively. Annual tile effluent quantities and discharges of nitrogen and phosphorus were not influenced by the timing or rate of manure application, nor soil management practices. This clearly indicated that weather conditions are the most influential variable in studying nutrient losses.

3. Annual total nitrogen and total phosphorus losses in soil sediment were highly variable from year to year. Increasing increments of manure rates significantly increased nitrogen and phosphorus losses in sediment during 1972, but the relationship did not hold in 1973. Average nitrogen and phosphorus contents in sediment were approximately 63% and 43% greater,

respectively, in 1972 as compared to 1973, mainly associated with increased rainfall and runoff in the former year.

4. Accumulative nutrient losses from winter runoff during the inclusive months from January to April was highly variable. Actual runoff values as averaged for the three rates of application for nitrogen were 16, 1 and 0.2 kg/ha for 1972, 1973 and 1974, respectively. Phosphorus values averaged 3.5, 0.2, and 0.01 kg/ha for the three respective years. The 35 t/ha rate applied in the winter across an array of weather patterns did not show any significant difference between the three years.

   Sediment losses of nitrogen and phosphorus were greatest during the winter of 1973. When dealing with sediment losses the condition of the soil surface is all important. With a given amount of precipitation, sediment yields would be greatest on an exposed surface as compared to an unexposed surface. The number of days of snow covered soil in 1972, 1973 and 1974 were 75, 39 and 64, respectively. In theory, soil protection from rainfall impact resulting from winter rains was lower in 1973, than in 1972 or 1974 because of less snow cover.

5. A snow melt event in 1972 served to illustrate the necessity to avoid spreading of manure on melting snow. The data clearly indicated that manure disposal during active thaw periods can result in excessive nutrient losses and high nutrient concentrations. Low rates of application (35 t/ha) disposed on frozen soil and then covered with snow before a thaw period resulted in acceptable nutrient losses when compared to areas that received no manure at all.

6. Residual nitrogen and phosphorus from previous manure applications influenced nutrient discharges the following year. Residual nitrogen exhibited a greater availability for runoff than residual phosphorus. Due to residual influences of manure, nutrient discharges during winter runoff can be greater from areas that received manure during the previous spring and summer in comparison to recent winter applied manure.

7. A soil structure variable (good versus poor) proved to be very important. Well managed soils had significantly lower nitrogen and phosphorus discharges in runoff especially during an abnormally wet year in comparison to poorly managed soils, because of improved soil structure. In both 1972 and 1973, surface runoff was twice as great on poorly managed soils.

8. The probability of high nitrate nitrogen concentrations (10+ ppm) in surface runoff was extremely small (range 1-14% of the time for the various treatments). However, the probability of high total soluble phosphorus concentration (0.1 + ppm) was great (range 37-81% of the time for the various treatments).

   Nitrate nitrogen concentrations in tile effluent exceeding 10+ ppm ranged from 18-82% of the time for the various treatments. However, the probability of total soluble phosphorus concentrations exceeding 0.1+ ppm ranged from 1-32% of the time.

9. Increasing rates of manure application increased the concentration of total nitrogen, available phosphorus and organic matter in the soil as a result of the three successive annual applications.

10. Corn responded significantly to increasing rates of manure application. However, the efficiency of utilization of nitrogen by the corn crop dropped markedly as the rate of application increased.

11. Hypothetical legislative controls simulated on a computer exerted their greatest influence over the dairy farms by way of reducing the acreage of land which is available for manure disposal. When this is coupled with low manure spreading rates, the controls simply prevent a herd size which is representative of today's dairy industry being reached without violating the restrictions.

12. Increasing cow/land ratios, resulting from legislation which requires that manure only be applied and utilized in a crop production program, increased the loss of nutrients to surface and ground water from farms with poor soils in two ways: (a) by increasing the proportion of land cultivated for feed requirements; (b) by increasing the rate of manure to be disposed of. On farms with productive soils, land which can be profitably cultivated will be cropped regardless of the size of the dairy herd, and most manure can be utilized in crop production. Thus cow/land ratios have little effect on losses from these farms unless large herd sizes are involved.

SECTION II

RECOMMENDATIONS

1. The soil should be utilized as a disposal medium for dairy manure. In order to minimize the potential for nutrient losses to the environment, the nutrient inputs from manure should match crop requirements for these nutrients. Soil limitations should also be considered.

2. Due to the wide range in climatic conditions within a year and between years and the ability of the soil-crop combination to minimize transport and utilize the nutrients in manure, the suggested maximum rate of application for non-winter disposal is 67 metric tons/ha (30 tons/acre).

3. Manure should not be spread on actively melting snow.

   Winter disposal activities should incorporate the disposal of manure on fields that are well managed (vegetative cover, well drained, etc.). Accumulated manure from storages should be spread in November or early December before the beginning of continuous snow cover. For daily spreading programs manure should be temporarily stored during periods of active snow melt. The suggested rate of application during the winter should approximate 35 metric tons/ha (15 ton/acre).

4. The transport of nitrogen and phosphorus from a disposal field can be minimized by practicing good soil management. This includes maintaining vegetative cover and returning plant residues on the disposal field.

5. Modeling approaches to farm-scale pollution problems may be feasible. However, assumptions and simplifications, while often necessary for conceptual and computational reasons, must not influence the results too greatly, or in ways which are unpredictable.

6. Modeling approaches dealing with the economics and response of manure applications should not be so general that they fail to take individual farm differences into account with particular reference to soil characteristics. This is especially true when guidelines or legislation are formulated for environmental protection.

SECTION III

LAND APPLICATION OF DAIRY MANURE

INTRODUCTION

Statement of the Problem

In the Northeastern and North Central U.S.A. there are about seven million milk cows or approximately one cow for each 13 acres of cultivated land. The annual manure production by these cows contains approximately 500,000 tons of nitrogen and 75,000 tons of phosphorus. This manure can be viewed as a valuable fertilizer and also as a major source of water pollution. Agriculture must learn how to maximize the former and minimize the latter aspect. Changes in agricultural practices have led to the farmer now being in a poorer position to deny 'unnatural' contribution of pollutants such as plant nutrients and other waste materials to surface and subsurface waters.

In many milksheds the sanitary code requires daily removal of manure from the dairy. As a matter of convenience, many dairymen spread manure daily on cropland, thus serving the dual function of disposing of the manure and utilizing the nutrients for crop production. The urgent need for manure utilization to lower the cost of fertilization of farm crops has led to a very great interest in land application of dairy manure. If one assumes that the value of farm manure is proportional to the fertilizer nutrient content, the value of manure to the farmer will increase with increasing fertilizer costs. This should make for more care in management and handling of manure on the part of farmers. Agricultural scientists should become more concerned about working out effective systems of utilization. Hopefully, the general public should look at both of these efforts with tolerance and favor.

Land application has been the traditional method for the recycling of animal wastes. Proper crop and land management practices should insure that land disposal of animal wastes will remain an environmentally acceptable disposal method. Poorly planned land disposal may result in subsequent runoff and subsurface percolation of nutrients. Because many of the organic and nutrient constituents of these animal wastes can be incorporated into the soil and utilized by crops, prior waste treatment may not be necessary. Effectiveness of land removal of pollutants from animal wastes is frequently dependent upon the type of cropping systems and the specific manure and land management practices.

Surface and subsurface drainage of precipitation is the basic transport mechanism for moving nutrients from a manured cropland area to surrounding areas. Hence the nutrient losses from manure spread on the land are intimately related to climatic events. There is no "average" year or event; climatic events occur in many different sizes and temporal distributions. In reality, regardless of how manure is handled there is always a finite probability of some loss. However, the probability of occurrence of a preset loss varies greatly among seasons and systems. In addition, the quantity lost will depend upon rates of addition per unit area and upon soil conditions such as infiltration rates and percolating rates through the profile.

Engineers customarily take into account many design parameters when planning water control structures with particular emphasis on the frequency of excessive storm events. Engineering practice tends to concentrate on "point sources" or a "point of design." The water outlet of a small drainage basin is such a point. Control of water quality and quantity at this point of design, unfortunately depends not entirely upon engineering practice, but also upon agricultural practice as well. This agricultural practice is widely regarded, by non-agriculturalists, as a major source of water pollution. The term "non-point pollution" or "diffuse sources" is generally used to characterize pollutants originating from agricultural sources.

On a microscale--individual field and individual farm scale-- the "non-point" sources are seldom ever non-point or diffuse. Agricultural and land management practices tend to dictate the source of and degree of water pollution from agriculture. For example, the practice of winter spreading of dairy manure originated from the sanitary code requirement of daily removal of manure from the barn.

The successful design of a land disposal operation for dairy manure demands an evaluation of all disposal parameters. Ideally we would like to derive what might be called "design parameters." By design parameters we mean adjusting ones disposal activities to account for the variability in the landscape such as soil differences and changes in topography as well as seasonal climatological changes.

Scope of the Work

Little information exists on the rates and methods for disposal of untreated and treated animal wastes on the land. Of prime interest would be the runoff and percolation associated with such disposal, the fate of the soluble nutrients, and the quantities of wastes that can be safely disposed of under different management systems.

This portion of the presentation will be concerned with dairy wastes and the concept will be demonstrated at the field plot level. The ultimate objective is to return dairy manure to the land with a minimum of expense and damage to water quality.

In order to demonstrate the effect of dairy manure disposal on water quality, surface runoff and deep seepage losses of nitrogen and phosphorus were measured in the field from plots that have received three different rates of free-stall dairy cow manure (35, 100, and 200 metric tons/ha) applied at three different times of the year (winter, spring, summer) on two different systems of soil management (good vs poor).

Well managed soils consist of plowing back plant residues after harvest. Poorly managed soils are those in which the plant residues have been removed at harvest time.

Nutrient loss comparisons are from all events producing runoff, as derived from natural rainfall from 1972-1974.

A preliminary set of guidelines for land disposal of manure has been developed and is based on the best available knowledge at this time.

In addition, a computer simulation model was developed for the particular purpose of examining the effect of some hypothetical legislative controls designed to reduce pollution related to dairy manure disposal.

LITERATURE REVIEW

The nitrogen content of dairy manure will depend on the care and management of the animals as well as the method of handling the manure prior to spreading. The typical dairy cow will produce approximately 115 gN/day in the urine and 100 gN/day in the feces (27). This is approximately equivalent to 5 kg of nitrogen per metric ton (10 lbs/ton) of fresh mixed urine and feces. Weeks (74), estimated the phosphorus content of dairy manure to be equivalent to approximately 0.85 kg in the feces and 0.05 kg in the urine per metric ton of fresh manure (1.8 lbs/ton).

Beyond certain limits nitrate, nitrite and ammonium nitrogen in water to be used for human or animal consumption are considered a health hazard. The current recommended maximum concentrations for drinking water are 10 mg/ℓ as the sum of nitrite and nitrate nitrogen and 0.5 mg/ℓ as ammonicial nitrogen (18). No criteria from the above source is established for phosphorus. Because oxidized inorganic nitrogen is readily soluble and mobile within the soil, concentrations far exceeding these nitrogen levels may be found in percolating water and surface waters from land receiving applications of manure (49). Witzel et al (78) have estimated that manure applications which are such that more than 15 kg/ha/yr (13.5 lbs/acre) of nitrogen pass beyond the root zone are sufficient to result in toxic levels of nitrates in ground water under some conditions.

It is usually assumed that phosphorus is immobilized in the surface layers of the soil and is not leached from the soil in significant quantities (73) and can be regarded as only a trace (13). However, Goodrich and Monke (25) point out that the ability of a soil to fix phosphorus is far from infinite and warn of the risk of ground water pollution with phosphorus from the incorrect design of soil waste disposal systems. Soluble organic phosphorus from manure sources carried in surface runoff may be somewhat resistant to adsorption on sediment particles. Taylor and Kuniski (70) observed that soluble phosphorus of manure origin was more persistent in runoff water than phosphorus from inorganic sources. It is unlikely, however, that phosphorus contamination would be a problem under application rates which are selected to avoid nitrogen contamination. Treated manures and effluents which may be low in nitrogen content may not satisfy this assumption. It would appear to be reasonable to restrict the application rate of manure to the soil based on the amount of nitrogen which is being applied if at the same time there is a simultaneous restriction preventing the amount of nitrogen being increased by fertilizer applications.

It is extremely difficult to say with any degree of certainty that any particular application rate of manure nitrogen should not be exceeded. Much depends on the time of application, the type of crop being grown and the type of manure. Marriot and Bartlett (49) applied 0, 785, 1570, 2355, 3140 and 3925 kg/ha (0, 700, 1400, 2100, 2800, and 3500 lbs/acre) of manure nitrogen to a crop of orchardgrass, and concluded that the first increment of 785 kg/ha of manure nitrogen was excessive and represented a pollution potential. Further study was necessary to find what the level between 0 and 785 kg/ha was acceptable. Weeks et al (74) showed that manure applications up to 430 metric tons/ha (192 tons/acre) resulted in leaching of nitrate down through the soil profile. At all application rates, the concentration of NO_3-N below the surface of the soil was considerably in excess of 10 mg/ℓ, but crop uptake appeared to control the level of leaching loss for application rates up to 94 metric tons/ha (42 tons/acre). They concluded that it was not economic to apply manure at rates greater than 45 metric tons/ha (20 tons/acre).

The timing of manure inputs to the soil has become a very important consideration, due to the objection of manure applications during the winter months. Loehr _et al_, (46) have discussed the timing of manure applications as it relates to precipitation, evapotranspiration and stream flow in the northeast. The main theme, from a pollution control standpoint, centers around the application of manure at a time when stream flow decreases and evapotranspiration begins to maximize.

Bryant and Slater (12) showed that, without manure, high losses of nitrogen may be expected in runoff during winter runoff. The high runoff losses during the winter appear to come primarily from the leaching of organic material on the soil surface. It would appear, then, that losses of nitrogen might be expected from winter spread manure, but not necessarily losses of manure solids. Similar results have been attributed to the spreading of manure on frozen soils (32, 55, 56). The situation is difficult to evaluate in the Northeast and North Central States because of the wide variation from year to year in frozen soil conditions. There is also a wide variation throughout this area in anyone particular year.

The studies of climatological processes and events reported here apply to the Northeastern and North Central U.S.A. Characteristically this area has one inch or more of snow on the ground for 100 to 140 days each winter (1). Garstka has exhaustingly reviewed the literature on snow melt and runoff (23). Without going into his presentation, it can be said that the presence of snow in these areas of the Northeast and North Central U.S.A. is very much a matter of chance. Lake positions and air mass movements are major considerations. Once snow has fallen, the soil beneath the snow may previously have been subject to "concrete freezing" or "honeycomb freezing." In the former case, water infiltration from melting snow may be difficult or impossible. In the latter case, infiltration may be good (68). Nutrients can be carried from the soil surface by melting snow, but they can also be carried by runoff from rainfall. Predicting equations for rainfall-erosion losses from cropland east of the Rocky Mountains are available (77). These equations were developed for relatively small areas, but in principle also apply to larger areas. Thus in terms of climatological events, snow melt and rainfall are of major consideration in moving nutrients from soil surface to water.

METHODS AND MATERIALS

Site Description and Sample Collection

The experimental installation was designed to measure the quantity and composition of surface and subsurface water flow. The experimental field is comprised of approximately 12 hectares of a Lima-Kendaia soil association at the Cornell Agronomy Research Farm near Aurora, New York. These soils are moderately to somewhat poorly drained and have a medium soil texture formed in strongly calcareous glacial till. They have 0.3-0.5 meter of moderately permeable silt loam over 0.3-0.8 meter of fine silt loam that is underlain by firm, dense, slowly permeable glacial till.

The design includes 24 plots, each 0.32 ha (61 by 53.5 meters) in size which were constructed in 1956. The study was maintained as a drainage experiment until 1969. From 1969-1972, these plots were used to evaluate water quality from farming systems using varying rates of mineral fertilizers. In the winter of 1972 free-stall dairy cow manure was substituted for mineral fertilizer.

Surface water was controlled by a series of small interceptor cross ditches and broad shallow runoff ditches up and down slope. Individual plots have surface slopes ranging from 2 to 4 percent. Runoff water was diverted into a 30.5 cm H-flume, located at each plot, where the flow volumes were measured. As water passed out of the flume, a subsample of approximately 1% was collected by an electrically driven Coshocton wheel. The sample was further divided by a splitter arrangement which could collect either 10 or 20% of the subsample. The integrated water sample taken over the entire period of flow was collected in an underground storage tank. After each runoff event a 250 ml subsample of the collected suspension was taken for analysis. The remaining suspension was pumped into an above ground drum and the sediment was flocculated with $CaCl_2$. After settling the supernatant was poured off and the sediment was retained for analysis. Each installation was insulated and contained a heating lamp to avoid freezing during the winter.

Subsurface flow of water was studied with the use of a single drain tile approximately one meter below the surface. These tile lines were centered in 12 randomly selected plots. The tile is 10 cm in diameter and empties into an underground metering tank. The effluent empties directly into a buffer chamber before flowing through a 90° sharp crested V-notch weir. A representative subsample of tile flow is collected from a uniform drip flow tube into a container. Accumulated tile effluent samples were collected on a weekly basis.

Management Practice and Disposal Techniques

The manure treatments for continuous corn were selected to approximate or to cover the range of practices utilized by dairy farmers in the northeastern and north central United States. Rates (35, 100 and 200 t/ha) were selected to approximate 160, 500, and 900 kg/ha of nitrogen (N). The 160 kg/ha rate closely correlates to the recommended needs of nitrogen for corn, while the 900 kg/ha rate characterizes the extreme.

Three different times of the year for disposal were selected on the basis of climatic conditions and restrictions associated with corn production. There has been much discussion in the past about:

a) Spreading manure on snow or frozen soil;
b) manure should be immediately plowed down; and
c) there are not suitable places to spread manure during the summer.

The winter, spring plow-down and summer topdress (applying manure on top of growing corn 0-5 cm high) applications were incorporated into the design to help answer these important questions.

Two systems of soil management were included. One involves the removal of all plant residues at harvest and is denoted as poor management. The other involves the reincorporation of plant material with the soil (good management). Corn harvested for silage is classified as a poorly managed soil since all of the plant residue is removed at harvest. Corn harvested for grain enables the reincorporation of the entire plant (except the grain) when the soil is plowed. The addition or subtraction of organic residues to the same plots has persisted for the last 16 years.

The design represents 18 different treatments (3 x 3 x 2). Three rates (35, 100, and 200 t/ha) combined factorially with three different times of disposal (winter, spring and summer) on good and poor managed soil. The 35 t/ha rate was replicated twice to give a total of 24 plots. Due to the limited number of plots being underdrained by a tile line, the 100 t/ha rate was not represented on tiled plots. The limited number of tiled plots were used to study nutrient concentration at the minimum and maximum rate of application.

Manure was supplied by a local dairy farmer who operated a 175 cow free-stall dairy operation. Each load of manure was weighed and application rates were within 0.5 metric ton. Manure applications were made with conventional manure handling equipment.

Chemical Analysis

Surface and subsurface water samples were centrifuged at 37,000 R.C.F. (relative centrifical force) for 30 minutes. The supernatant was analyzed for NH_4-N which involved the reaction of ammonium, phenol and hypochlorite in an alkaline medium (61). NO_3-N was determined by reducing nitrate to nitrite by copper and hydrazine sulfate in an alkaline solution (35). Soluble inorganic P was determined according to a modification of Fiske and Subbarow (19) procedure. Total soluble PO_4-P is analyzed by hydrolyzing polyphosphates and oxidizing organic phosphate by heating with potassium persulfate. The resulting ortho-phosphate is determined on an autoanalyzer (53).

Sediment samples were analyzed for total nitrogen, total phosphorus and organic matter. For total nitrogen (Kjeldahl), the soil is digested with sulfuric acid, potassium sulfate and copper sulfate to convert organic nitrogen to ammonia. The ammonia is then titrated with standard sulfuric acid in a boric acid solution (11). Total phosphorus is determined by ashing the soil with magnesium nitrate. The residue is heated with hydrochloric and nitric acid to hydrolyze polyphosphates to orthophosphate. Orthophosphate in the resulting solution is determined by reacting with molybdic and vanadic acids (53). Organic matter is determined by leaching the soil with a solution of potassium dichromate. Upon addition of sulfuric acid, the heat of reaction is used to oxidize soil organic matter. Excess dichromate is measured by titration with ferrous sulfate (26).

Manure samples were taken from each spreader load of manure. Representative samples for analysis were composite samples of three spreader loads. Dry matter content was determined on one subsample. A second subsample was homogenized with an equal weight of water in a blender for 1 minute. Subsamples of this homogenate were analyzed for ammoniacal nitrogen, total nitrogen, soluble inorganic P, total soluble P and total P. Ammonia was determined by distillation with magnesium oxide (11). Total nitrogen, and the various forms of phosphorus were determined by the previously mentioned procedures.

RESULTS AND DISCUSSION

The 1972 calendar year was extremely wet in the Northeastern U.S. and a tropical storm on June 21-25 caused heavy rainfall and flood damage. Figure 1 illustrates the distribution of precipitation throughout the year at the Aurora experimental farm where this study was conducted. There are three significant climatological events: 1) A thaw period in early March; 2) hurricane Agnes in June which delivered over 17 cm of rainfall, a 1 in 100 year storm frequency;

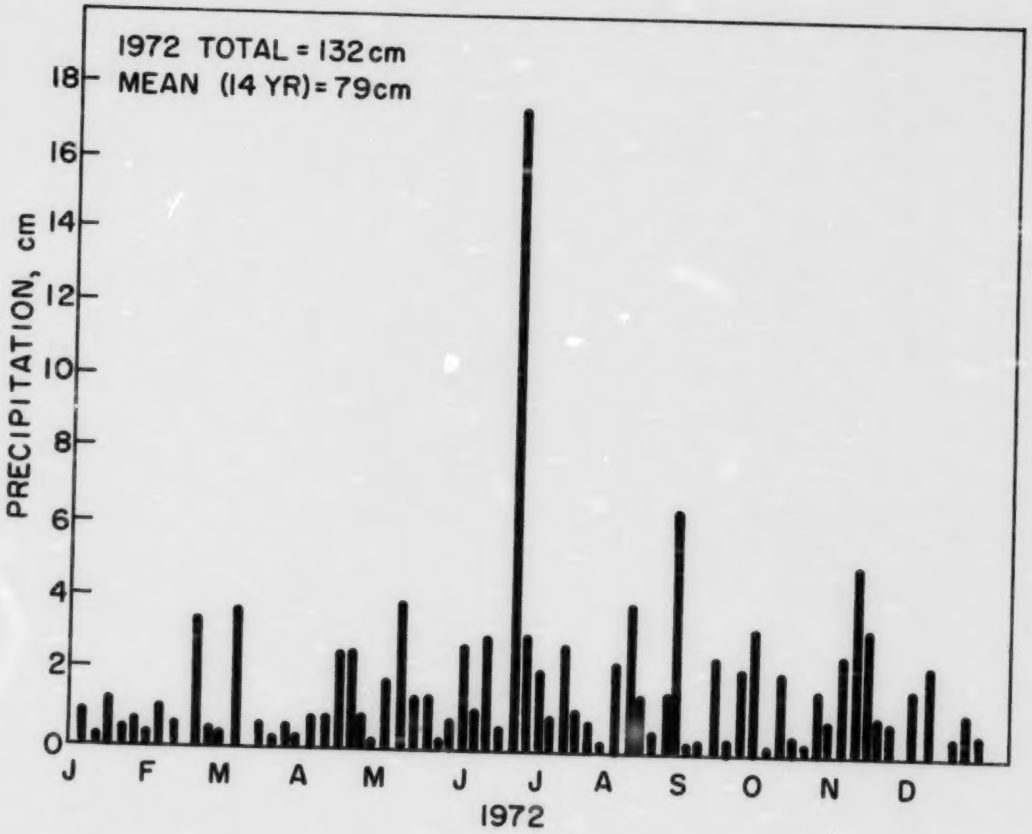


Figure 1. Annual precipitation divided into 5 day periods at Aurora, N.Y. 1972.

and 3) an intense storm in August which delivered 6.5 cm of rain in approximately one hour, a 1 in 50 year storm frequency. There was 132 cm of rainfall in 1972, a 67% increase in comparison to the 'normal.' The 'normal' is based on a 14 year mean (79 cm) from 1952-1966.

With a significant increase in precipitation, it could be assumed that removal of nutrients by water would increase accordingly. Consequently, the losses of nutrients from the land in 1972 may be higher than that which would normally be expected.

Annual precipitation during 1973 was only 2 cm above the 14 year mean (Figure 2). Nutrient losses from the application of dairy manure during 1973 may be more nearly typical of what can be expected than losses incurred during 1972. The two major peaks in Figure 2 were derived from winter rainfall in late March and the first week of April.

The Aurora experimental farm is located in central New York and has a climatological pattern similar to many of the northeastern and central states. Figures 3 and 4 are illustrations comparing two important weather parameters among states. More specifically, Figure 3 denotes distribution of the rainfall factor R in Wischmeier and Smiths (77) universal soil loss equation. The R factor is a function of the kinetic energy and intensity of rainfall and is a measure of the relative erosiveness of a rainfall event. The values given in Figure 3 are the annual sums of the individual R values. The average of 100 for New York is fairly typical of the northeastern and north central regions. The number of days during a year in which the landscape is covered with 2.5 cm or more of snow (Figure 4) in central New York is also typical of the same geographic regions as discussed for the previous example.

From these illustrations, it is conceivable that the data presented for central New York may be typical of the array of nutrient losses that can be expected from a much broader geographical area.

Nutrient Discharges

The manure treatment schedule for the past three years is presented in Table 1 and should serve as a guide throughout the text. In general, manure applications for a particular disposal period (winter, spring or summer) was made within a time span of 4-6 days. In 1972 the winter and spring applications were made over a longer period of time because of the interruption of adverse weather. The climatological sequences during the winter application in 1972 posed a real problem in terms of spreading but created some interesting data.

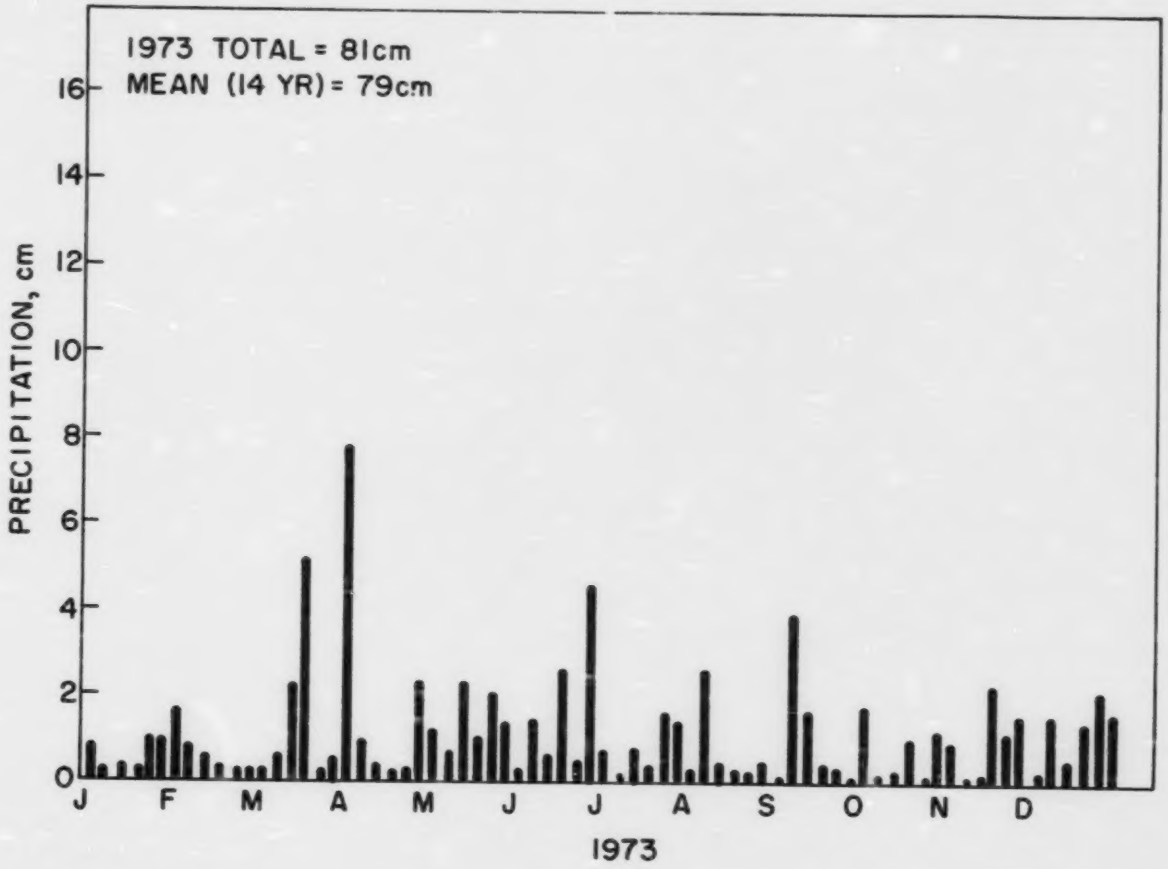


Figure 2. Annual precipitation divided into 5 day periods at Aurora, N.Y. 1973.

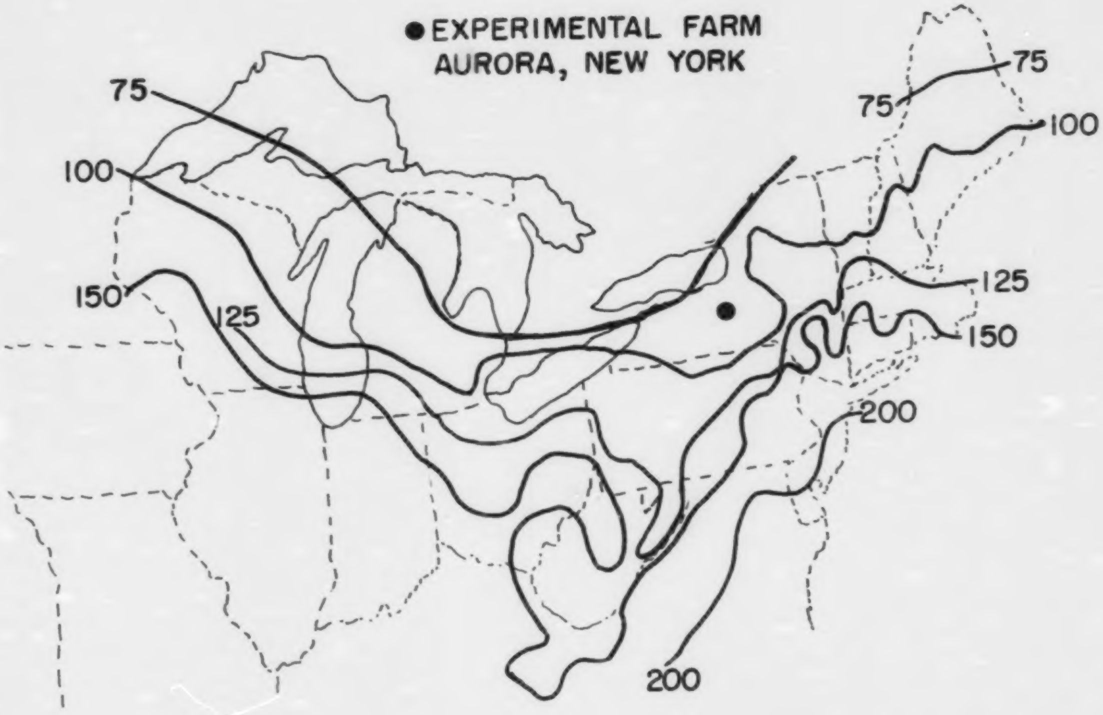

● EXPERIMENTAL FARM
AURORA, NEW YORK
75
100
150
125
75
75
100
125
150
200
200

Figure 3. Average of the rainfall factor (R). Taken from Wischmeier (77).

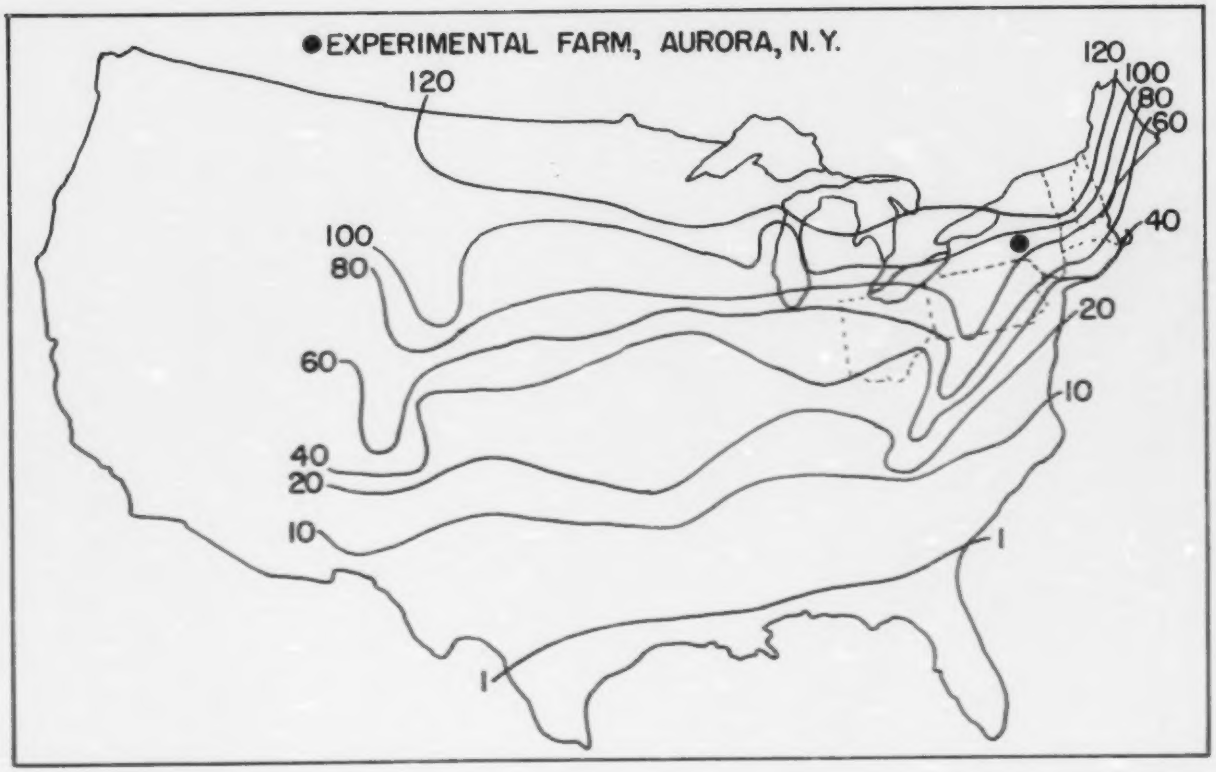

● EXPERIMENTAL FARM, AURORA, N.Y.
120
100
80
60
40
20
10
1
120
100
80
60
40
20
10
1

Figure 4. Average annual number of days with snow cover exceeding 2.5 cm (1).

Table 1. TREATMENT SCHEDULE, JANUARY 1, 1972 - JUNE 1, 1974

Time of application	Rate of applic, metric tons/ha	Misc	Date
Winter	35, 200 100		Feb. 15-18, 1972 Feb. 29, 1972
Spring	35, 200 100		April 27-May 2, 1972 May 15, 1972
		Plowed	May 20-26, 1972
		Corn Planted	May 30, 1972
Summer	35, 100, 200		June 6-14, 1972
		Corn Harvested	Oct. 1972
Winter	35, 100, 200		Jan. 12-17, 1973
Spring	35, 100, 200		April 19-21, 1973
		Plowed	April 23-26, 1973
		Corn Planted	May 24, 1973
Summer	35, 100, 200		June 6-21, 1973
		Corn Harvested	Oct. 1973
Winter	35, 100, 200		Jan. 8-10, 1974
Spring	35, 100, 200		April 23-26, 1974
		Plowed	April 26-30, 1974
		Corn Planted	May 16, 1974
Summer	35, 100, 200		May 27-June 2, 1974

Timing and rate of application as well as soil management are important variables to consider in nutrient runoff studies. The 35 t/ha rate was truely replicated at all treatment levels to obtain an estimate of experimental error. The remaining plots receiving either 100 or 200 t/ha as an annual rate, applied either in the winter, spring, or summer on either a good or poorly managed soil, were not replicated.

The section dealing with methods and materials notes that since only one-half of the total number of experimental plots (12 out of 24) contain a drain tile, the 100 t/ha rate was not represented on these plots. Tiled plots were reserved to study nutrient concentrations at the minimum (for one replicate) and the maximum rates of application (2 rates x 3 disposal times x 2 soil mg't practices x 1 replicate = 12 individual treatments). Consequently, quantitative nutrient losses in runoff and sediment for the intermediate rate of application (100 t/ha) over all levels of timing and soil management may be biased upwards due to the lack of underdrainage.

Annual Nutrient Losses -

There is some question as to the value of comparing annual losses between various treatments because there are usually only a few storm events during a hydrologic year which may account for a large percentage of an annual loss, and perhaps individual storm losses are more meaningful. However, the authors feel that annual nutrient losses are extremely meaningful from two standpoints. These are; (a) to study the behavior of a particular dairy manure treatment over time as it is influenced by a series of seasonal changes, hence, cumulative climatological sequences and (b) in some years, climatological sequences may be such that individual storm losses appear minor, but the cumulative losses throughout the year may be significantly high.

Surface runoff - The annual losses of inorganic nitrogen (NH_4-N + NO_2-N + NO_3-N) and total soluble phosphorus inorganic + organic) in runoff are presented in graphic form in Figure 5. There is a marked difference in N and P losses between 1972 and 1973 with the latter year being much less. Individual plot losses and tests of statistical significance are presented in Tables A1, A2 and A3 of the Appendix. This illustration served to support the contention that nutrient losses from the land surface for a given treatment is highly variable from year to year. The most influential variable, of course, is the weather. Reference to Figures 1 and 2 indicate that during 1972 considerably more rainfall occurred while a more 'normal' amount of rainfall occurred in 1973.

With reference to both nitrogen and phosphorus in Figure 5, the greatest losses during 1972 occurred at the 100 t/ha rate and during the winter application. By referring to Table A1 of the Appendix,

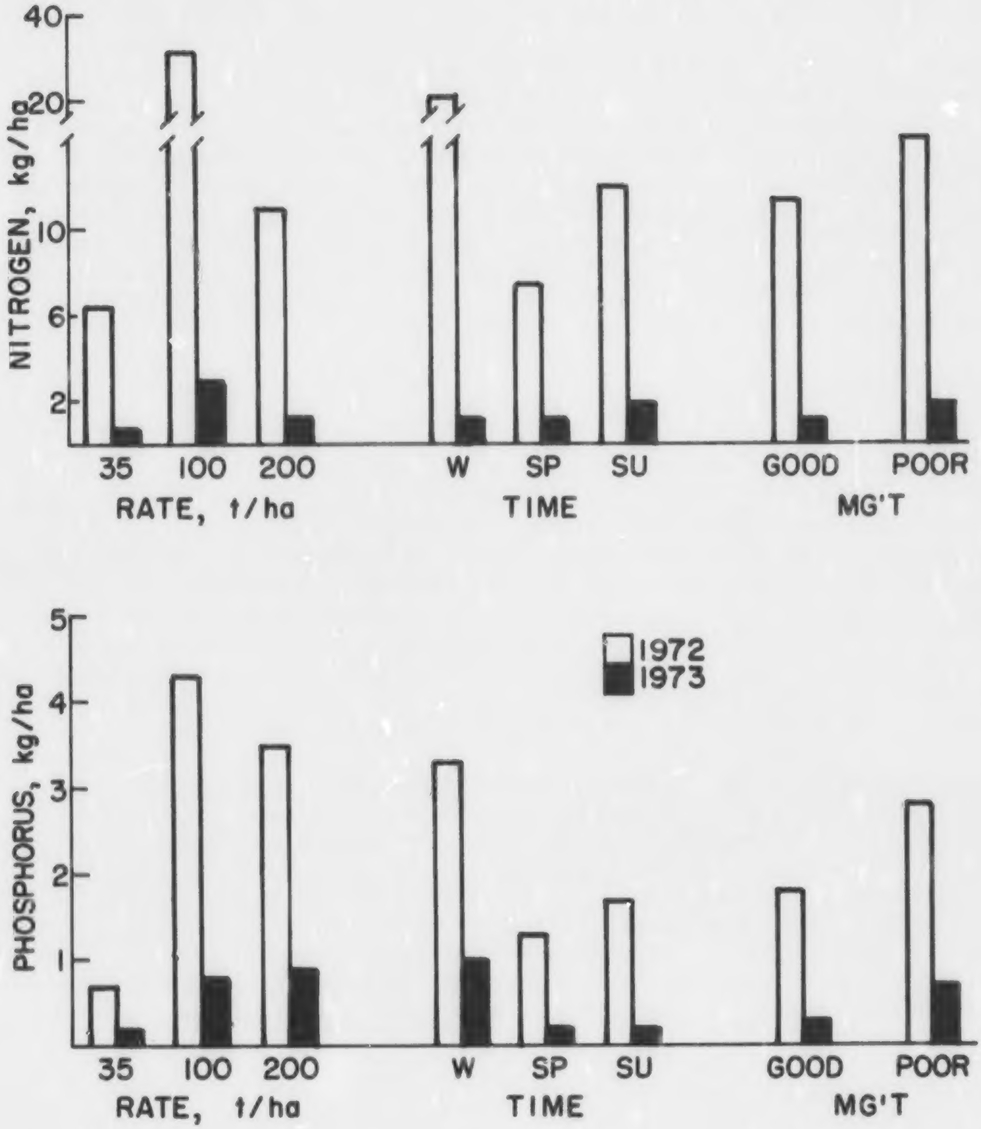


Figure 5. Yearly comparisons of inorganic-N and total soluble-P in surface runoff. W, SP and SU denote winter, spring and summer applications.

it is obvious that nutrient losses at the 100 t/ha rate spread during the winter for both good and poor soil management was responsible for these peaks. Unlike the winter application of the 35 and 200 t/ha treatments, the 100 t/ha rate was delayed, due to adverse weather, and spread on dense melting snow. This surface soil condition resulted in unfavorable nutrient losses, especially on a poorly managed soil. A more thorough explanation of this phenomena is presented in the section dealing with selected runoff events.

There are many other independent variables that are important when considering nutrient losses from the land surface. Soil management is one of the more important variables. Soil management played an important role during the unusually wet year of 1972. Good soil practice (plowing back plant residues) resulted in a lower discharge of nitrogen and phosphorus as compared to a poorly managed soil (removal of plant residues after harvest). Surface runoff during 1972 was approximately 100% less on plots that were well managed in contrast to poorly managed treatments (Table A3 Appendix). The reduced runoff and consequent lower nutrient discharge can be attributed to an improved soil structure, hence greater water permeability, associated with the well managed soils. Using aggregate stability (the percentage of water stable aggregates) as a relative index of soil structure, well managed plots were approximately 30% higher than poorly managed ones (59% versus 45%).

The addition or removal of plant organic matter, as it influences soil structure, may become erased in future years by the larger additions of organic matter from manure. Even if this phenomenon is masked by future manure additions, the physical presence of a plant residue cover on the soil surface after harvest on well managed soils would aid in the reduction of surface runoff.

Surface water nitrogen losses during 1973 (Figure 5) were slightly higher for the 100 t/ha rate regardless of the time of application while losses associated with the time of application and soil management practices were essentially identical. Phosphorus losses during this year were significantly higher for the two highest rates as well as for the winter application. Well managed soils reduced phosphorus outputs by 130% as compared to poor soil management.

Whether it be nitrogen or phosphorus losses that are of concern, it is evident that the lower rate of application (35 t/ha), regardless of the time of application studied, results in lower nutrient loadings. With respect to time of application, manure applied in the spring, regardless of the rates studied, and plowed down shortly afterwards, also results in the lowest nutrient loading.

Soil sediment - Direct organic matter losses from the field receiving manure are calculated in the sediment loss. Table A6 of the Appendix gives the organic matter losses and shows that for the average of the two years, organic matter losses were 64, 196, and 208 kg/ha for the 35, 100 and 200 t/ha manure rates respectively. Consequently, total N and total P in sediment is influenced by the nitrogen and phosphorus associated with the sediment plus that portion associated with the organic matter. The percentage of the sediment that was organic matter as averaged over two years ranged from 7 to 14 percent for the values plotted in Figure 6.

The loss of total N and total P in soil sediment from the experimental plots was higher in 1972 than 1973 (Figure 6) because of the greater amount of surface runoff associated with the 1972 calendar year. Individual plot losses and test of treatment significance for sediment are presented in Tables A4, A5 and A6 of the Appendix.

There was a significant increase in sediment nitrogen and phosphorus as the rate of application was increased during 1972. For 1973, however, there was a significant increase in nitrogen losses for the 100 t/ha rate in comparison to the 35 and 200 t/ha rates. The increases in nitrogen and phosphorus were directly associated with the increased rate of organic matter loss (Table A6, Appendix).

The affect of timing of manure application and sediment losses for both nitrogen and phosphorus behave similarly within each year. The only real treatment difference that occurred in 1972 was that the summer application resulted in lower discharges of nitrogen and phosphorus than the spring application but was not significantly less in comparison to the winter application. During 1973, timing of manure application had no real effect on nitrogen and phosphorus loadings resulting from sediment movement.

In many cases, soil sediment and associated nitrogen and phosphorus losses may not be a function of rate or timing of manure application but rather a function of the soil and its topography. The greatest losses of particulate, nitrogen and phosphorus occurred from a poorly managed plot receiving 200 t/ha applied in the spring (Tables A4 and A5 Appendix), in both 1972 and 1973. These losses are not characteristic of the treatment but rather a function of the soil characteristic. This poorly managed plot contains a complex slope (surface topography) which runs in two directions and is more strongly sloping than any other plot in the experiment. Since runoff and erosion is partly a function of slope, one would expect an increase in nutrient losses with an increase in slope gradient. This treatment showed the highest loss for the month of June during 1972, which was due solely to hurricane Agnes. This single runoff event on the poorly managed

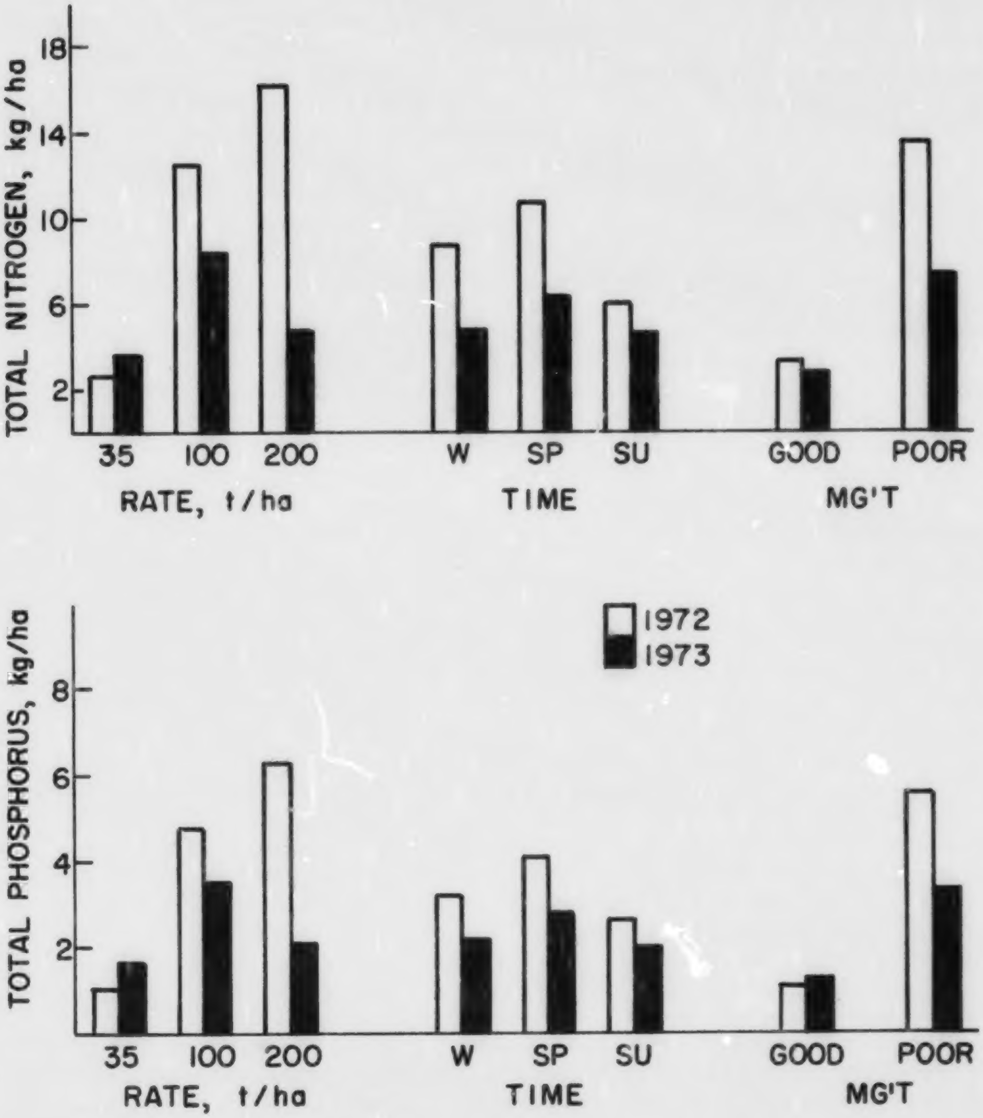


Figure 6. Yearly comparisons of total-N and total-P in sediment. W, SP and SU denote winter, spring and summer applications.

plot accounted for 84% of the total soil loss and 83, 70 and 75% of the total N, total P and organic matter losses respectively. A more detailed analysis of the above is presented in the section dealing with selected runoff events.

The effect of soil management practice behaved similarly for sediment losses of nitrogen and phosphorus (Figure 6) as it did for surface water nutrient losses (Figure 5). As discussed previously, a well managed soil (one with improved soil structure) promotes greater infiltration and percolation through the soil, hence a smaller percentage of the rainfall appears as surface runoff. Reduced surface runoff causes an understandable reduction in sediment movement and reduced nutrient loadings. Notice that there is a much greater difference between good and poor soil management during a wet year (1972) in contrast to a more 'normal' year (1973).

Extreme care should be used when interpreting the nutrient loading from surface water and sediment. The losses of nitrogen and phosphorus presented are considered to be an overestimate of what would naturally occur in a watershed. Firstly, dairy manure was spread from adjacent to, to a maximum of 60 meters from the interceptor ditch which diverts overland flow to the sampling device. In actual practice, this would be synonymous with spreading manure adjacent to a stream bank. This type of disposal is not commonly practiced if not for common sense, then because of stream location with reference to cultivated land. Secondly, the behavior of nitrogen and phosphorus in transport from a disposal field to a water course is not well defined. Nutrient loadings to a water course would depend on length of travel, additional diluting water, topography, soils, vegetation, etc. Thirdly, loading rates of manure approaching 100 to 200 metric tons/ha over extensive areas of a given watershed is not a common occurrence. The data presented, however, becomes extremely important when studying the behavior of nitrogen and phosphorus losses from a well defined disposal field.

Tile effluent - The section dealing with methods and materials points out that due to the limited number of instrumented tiled plots, one-half of the 35 t/ha treatment (or 1 replication) and all of the 200 t/ha treatments were tiled. It was felt, with a limited number of internally drained plots, the minimum and maximum rates of application should have priority.

Tiled plots consisted of a single 10 cm drain tile running the full length of the plot (60 m), located at the center at an approximate depth of 1 meter. The field design consisted of two rates of application (35 and 200 t/ha), each at one of three disposal periods (winter, spring and summer) on either a well managed or poorly managed soil for a total of 12 treatments (2 x 3 x 2).

The quantity or concentration of nitrogen and phosphorus in tile discharge is not a reliable indicator of that which will eventually find its way to the ground water reservoir. Artificial internal drainage alters the natural pathways of water and consequently, nitrogen and phosphorus movement. Surface infiltration of water into the soil in this experiment is rapid (approximately 5 cm/hr). The dense subsoil and underlying glacial till below the plow layer has a saturated hydraulic conductivity of less than 0.25 cm/hr. Restricted downward movement of water begins at the bottom of the plow layer due to a plowpan which has developed over the years.

Infiltrating water moves through the permeable plow layer. Upon encountering the restrictive layer, a perch water table develops. Some of the water slowly percolates into the subsoil. The remainder begins to move laterally downslope and may possibly reappear at the surface some distance removed. A tile trench (filled with permeable material during construction) which crosses the field perpendicular to laterally moving water, intercepts a portion of this water on the upslope side, and discharges it through the tile. One would speculate that since lateral flow volumes are reduced, due to interception by the trench, quantitative downward movement of water might also be reduced.

Since water is more rapidly removed from the soil by tile drainage than by natural drainage in these soils, so is the more rapid removal of nitrogen and phosphorus. The form in which nitrogen is removed from the soil is also altered. Within the vicinity of its influence, artificial drainage tends to achieve an aerobic environment because of the removal of soil water. Aerobic conditions would favor the oxidized form of inorganic nitrogen (NO_3-N). When these imperfectly drained soils are not artificially drained, the likelihood of nitrogen removal by denitrification is greater than under artificially drained situations.

The natural pathway of phosphorus transport, like nitrogen is also altered by tile drainage. In non-tiled drained situations, phosphorus in solution would move less rapidly in comparison to a more rapid removal of water via a tile line. Less rapid removal (increased retention time) and additional percolation of water into the subsoil would enhance phosphorus fixation. In essence, the quality of tile effluent is not representative of the quality of soil water that is naturally transported through the soil profile.

Although one may appreciate the problems encountered with evaluating tile drainage effluent for given water transport pathways, treatment comparisons can be difficult to assess. Due to natural soil heterogeneity, each respective tile line, although the same diameter and length, may be draining a proportionally different volume of soil. If drainage volumes become partially independent of the applied manure treatment, then nitrogen and phosphorus discharges also become partially independent of these imposed treatments. The investigator must realize that treatment differences need to be great to be significant.

Annual flow and nitrogen and phosphorus discharges in tile effluent are given in Table 2 for the respective treatments. Because of the high degree of variability in drainage characteristics, treatment effects did not significantly influence tile effluent discharges. Even if the independence between tile effluent discharge and treatment was an overestimate, absolute numerical differences in terms of nitrogen and phosphorus losses were not very great.

The data of Table 2 are the discharges per single tile line. If one wants to assume that the drainage areas per tile line are identical, a calculation on a constant per unit area basis can be made. If it is assumed that each tile line drains the entire upslope portion of the plot plus 3 meters on the downslope side, a conversion factor of 5.23 can be used to calculate nitrogen and phosphorus discharges on a per hectare basis. Table 3 is a presentation of adjusted tile effluent discharges on an area basis. The ratio between treatment means are identical to Table 2 since a constant factor was used for adjustment. Water and nutrient discharges, however, are approximately 5 times greater on a per hectare basis, in comparison to a per tile line discharge.

Selected Runoff Events -

The comparison of various runoff and associated climatological events serves to point out several important factors which should be considered when establishing parameters for any system in which the weather is a variable. This is especially true for land disposal of animal wastes since runoff is the principal means of nutrient transport.

The design of manure management parameters for an 'average' year, in terms of climatic events, is difficult to assess since an average year exists in definition only. In the same sense, no two climatic events will be the same nor will the antecedent conditions pertaining to them be the same.

A particular manure management treatment may behave quite erratically from one year to the next since the independent variables controlling nutrient discharge are in constant oscillation. However, the comparison of the behavior of manure treatments for any given climatological event becomes meaningful since a good many of the independent influences concerning nutrient discharges are acting similarily.

Table 2. FLOW, INORGANIC NITROGEN AND TOTAL SOLUBLE PHOSPHORUS DISCHARGES IN RANDOM TILE LINES. 1972, 1973.[a]

Treatment	Flow, m^3 1972	Flow, m^3 1973	Flow, m^3 Ave.	N, kg 1972	N, kg 1973	N, kg Ave.	P, kg 1972	P, kg 1973	P, kg Ave.
Time									
Winter	984a	358a	671a	10.4a	7.0a	8.7a	0.05a	0.31a	0.19a
Spring	1378a	720a	1049a	12.8a	10.4a	11.6a	0.09a	0.07a	0.08a
Summer	857a	270a	563a	10.9a	5.4a	8.2a	0.17a	0.01a	0.09a
Rate, t/ha									
35	1164a	461a	814a	10.7a	5.0a	7.8a	0.04a	0.01a	0.02a
200	981a	437a	709a	12.1a	10.2a	11.2a	0.17a	0.25a	0.21a
Soil mg't									
Good	987a	347a	662a	11.7a	5.7a	8.7a	0.06a	0.03a	0.04a
Poor	1168a	552a	860a	11.0a	9.5a	10.3a	0.14a	0.23a	0.17a

[a] Means followed by the same letter are not statistically significant @ 5% level.

Table 3. ADJUSTED FLOW, INORGANIC NITROGEN AND TOTAL SOLUBLE PHOSPHORUS DISCHARGES IN RANDOM TILE LINES. 1972, 1973.[a]

Treatment	Flow, m^3/ha 1972	Flow, m^3/ha 1973	Flow, m^3/ha Ave.	N, kg/ha 1972	N, kg/ha 1973	N, kg/ha Ave.	P, kg/ha 1972	P, kg/ha 1973	P, kg/ha Ave.
Time									
Winter	5150	1874	3512	54.4	36.6	45.5	0.26	1.62	0.99
Spring	7213	3769	5491	67.0	54.4	60.7	0.47	0.37	0.42
Summer	4486	1413	2947	57.0	28.2	42.9	0.89	0.05	0.47
Rate, t/ha									
35	6093	2413	4261	56.0	26.2	40.8	0.21	0.05	0.10
200	5135	2287	3711	63.3	53.4	58.6	0.89	1.31	1.10
Soil mg't									
Good	5119	1816	3465	61.2	29.8	45.5	0.31	0.16	0.21
Poor	6114	2889	4501	57.6	49.7	53.9	0.73	1.20	0.89

[a] Flow and quantities adjusted on an area basis by assuming a constant drainage area for each tile line.

The rate and timing of manure applications is an important consideration in any manure management scheme. This section will deal with the response of rate and timing of application for a series of selected runoff events.

Table 4 is a listing of the several selected storms for this discussion. An estimate of the contributing rainfall is necessary for events resulting from several days of rainfall. The column reserved for remarks indicates the type of climatological situation that occurred. Table 5 points out the relative severity associated with these runoff events. The quantity of runoff and soil loss is calculated as an average over all 24 experimental plots to serve as a relative guide to severity. The runoff and soil losses are also calculated in terms of the percent of the annual using the calendar year for annual computation.

Each runoff event will be discussed separately to bring out the characteristics of both the precipitation and surface soil conditions.

Figures 7 through 15 are the resultant nutrient losses of inorganic nitrogen (NH_4-N + NO_3-N) and total soluble phosphorus in surface water effluent and total nitrogen and total phosphorus in sediment. Each figure is self explanatory as to the rate of manure application and the time of the year the manure was applied. The losses are averaged over both soil management practices to produce the main effects of rate and timing. The interaction between rate and soil management practice will be discussed where appropriate. The verticle scale for each figure was changed to enhance clarity, therefore comparisons of relative magnitudes of nutrient losses from one figure to the next should be made with caution.

Selected runoff events were chosen on the basis of the type of climatological event and also to give a broad spectrum over seasons. The runoff events presented are only a small segment of the total runoff that occurred over the years. The sum of the individual events are presented in the section dealing with annual nutrient discharges.

One random variable which confuses comparisons is experimental plot to plot variability. It is inevitable that the slopes, infiltration rates, and internal percolation rates vary from plot to plot. This means that some of the differences among treatments are not treatment effects per se, but rather the effect of the nature of the soil to which the treatment was applied. Judgments about whether affects are due to treatment or are a consequence of plot characteristics are based on an intimate knowledge of the plots themselves

Table 4. CHARACTERISTICS OF SELECTED RUNOFF EVENTS.

Storm no.	Runoff date(s)	Estimate of contributing rainfall, cm	Snow cover, cm	Remarks
154	2/28-29/72		28	Snow melt, water equivalent approx. 3.3 cm.
243	6/21-26/72	17.4		Hurricane Agnes. Max. hourly intensity = 1.5 cm
261	8/27/72	6.8		Maximum hourly intensity = 6.4 cm
288	12/4-7/72	3.8		Sum of 5 day rainfall
311	3/17-19/73	6.6	1	Sum of 5 day rainfall
315	4/1-6/73	8.0		Sum of 6 day rainfall
338	12/22-27/73	1.2	20	Snowmelt followed immediately by rain
349	2/22-24/74	1.3	1	Snowmelt followed by rain
371	6/11/74	4.6		Total rainfall occurred in 75 minutes.

Table 5. RELATIVE SEVERITY OF SELECTED RUNOFF EVENTS.[a]

Storm no.	Runoff date(s)	Runoff, cm	% of annual	Soil loss, kg/ha	% of annual
154	2/28-29/72	2.08	14	103	3
243	6/21-26/72	5.51	32	1331	47
261	8/27/72	0.76	4	181	12
288	12/4-7/72	9.91	5	20	1
311	3/17-19/73	2.21	41	884	77
315	4/1-6/73	1.96	36	161	14
338	12/22-27/73	0.25	5	3	< 1
349	2/22-24/74	0.14	-[b]	7	-
371	6/11/74	0.22	-	90	-

[a] Averaged over all experimental plots.

[b] Data not available for entire 1974.

as well as upon statistical treatment of the data. This type of soil variability even within a small area is not at all uncommon. The larger the watershed, the more difficult it becomes to characterize the controlling independent variables and to define the inherent variability.

Referral from time to time to the treatment schedule of Table 1 in the section dealing with annual nutrient losses may be necessary to help orient the reader.

February, 1973 - The first selected event was the result of a snowmelt that occurred during winter disposal. The first manure application began on February 15, 1972 for the winter applied treatment. The soil was frozen and covered with 2 cm of snow. The 35 and 200 t/ha rates were completed in four days. Upon completion, 48 cm of snow fell which delayed the application of the 100 t/ha rate until February 29. By this time, the snow had increased considerably in density due to melt, having a depth of approximately 28 cm. This soil surface condition gave an opportunity to spread manure on dense melting snow over frozen soil, the worst possible condition that could occur during winter activity with reference to melting snow and frozen soil. When the 100 t/ha rate was applied, the machinery cut ruts into the snow which further enhanced channelization of the runoff water.

Figure 7 shows the extremely large and significant discharges of nitrogen and phosphorus for the 100 t/ha loading rate in comparison to the 35 and 200 t/ha rates even though the rate was approximately halfway between the minimum and maximum amounts applied. Spreading of manure on deep melting snow is a practice not commonly utilized by dairy farmers. It is not very often that the soil is able to support heavy machinery during snow melt periods. In essence, spreading wastes on deep melting snow is uncommon because of the soil restriction and not due to a management decision.

Although no control plots exist in the experimental design, the remaining 16 plots (24 total) slated for spring and summer application (8 apiece) serve as control plots for this event and are presented in the upper half of Figure 7. The nutrient discharges from the control result from the residual nitrogen and phosphorus present in the soil. It is interesting to note that losses from the 35 t/ha rate for both surface water and sediment were less than the control. This serves to denote that low loading rates even on a frozen soil may be within acceptable tolerances.

Soil management played a very important role in this runoff event, especially for the 100 t/ha rate. Table 6 is a breakdown of the loading rate split into the respective soil management practices.

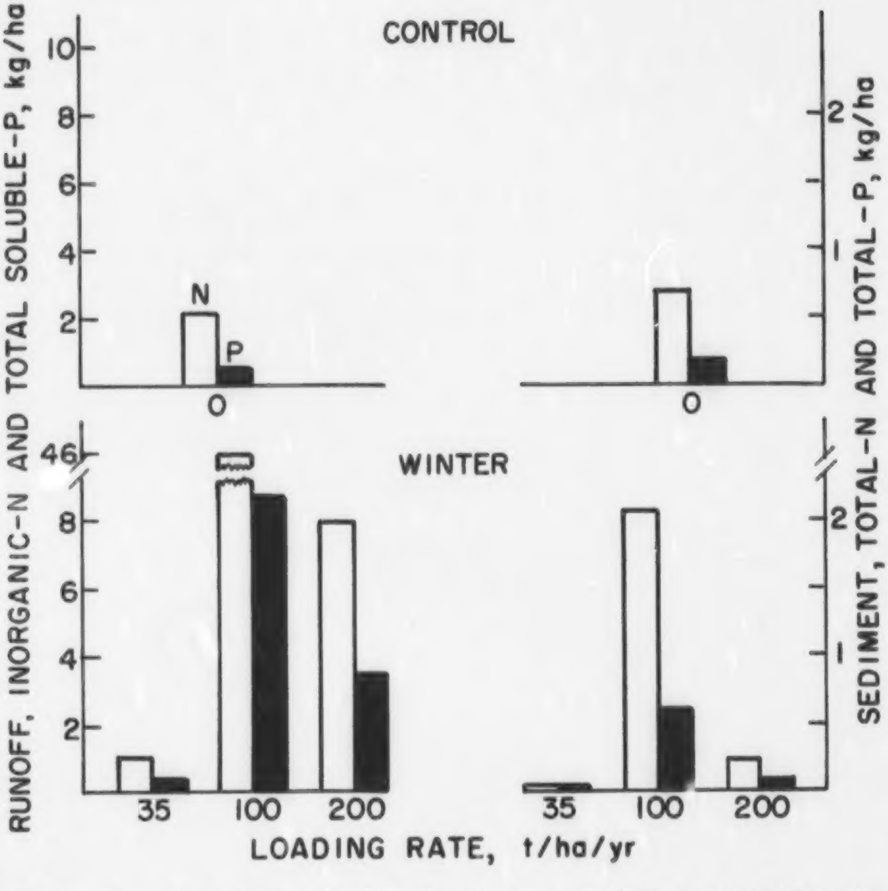


Figure 7. Nitrogen and phosphorus losses from a snowmelt event with respect to loading rate. 2/29/72.

Table 6. DAIRY MANURE LOADING AND SOIL MANAGEMENT UNDER CONDITIONS OF SNOWMELT AS A CONSIDERATION IN NUTRIENT DISCHARGE. 2/29/72[a]

Loading rate, t/ha/yr	Soil mg't	Surface runoff, kg/ha N	Surface runoff, kg/ha P	Sediment, kg/ha N	Sediment, kg/ha P
35	Good	0.6 a	0.2 a	0.02 a	0.01 a
	Poor	1.4 a	0.4 b	0.08 a	0.06 a
100	Good	25.1 a	5.0 a	2.91 a	0.58 a
	Poor	66.2 b	12.9 b	1.18 b	0.82 a
200	Good	4.2 a	1.9 a	0.24 a	0.11 a
	Poor	12.0 b	4.8 b	0.19 a	0.07 a

[a] Values followed by the same letter are not significantly different @ 5% level.

It is actually the interaction between rate and soil management. There is considerable difference between good and poor practice (return of plant residues vs their removal for the past 16 years) at the two higher rates of application. The greatest loss occurred at the 100 t/ha rate on a poorly managed soil. Long term poor soil management practices have made this plot relatively erosive. Lack of underdrainage for both management practices for this rate of application further compounds the problem by not providing partial relief for excess water.

June, 1972 - The runoff event of June 26, 1972 resulted from Hurricane Agnes. Rainfall was 17.4 cm over a five day period with moderate intensities on an already saturated soil. The long duration of the storm caused considerable damage to the landscape. At the time of this event, the spring and summer applications of manure had been applied. The winter and spring treatments had been plowed down and the summer applied manure remained on the soil surface. The corn was less than 0.3 meters high. The frequency of this rainfall event had been estimated by climatologists to occur once in 100 years.

The general behavior of nutrient losses for this event are quite erratic for the rate and timing of application (Figure 8). For surface water nitrogen and phosphorus contents, the output in the effluent is fairly constant for the summer application regardless of the rate, owing to the fact that the manure is exposed on the soil surface and sufficient nitrogen and phosphorus is available for removal. The erratic behavior of the rate and timing treatments as a result of a hurricane can be explained by the very important fact that once a soil becomes saturated, the imposed treatments no longer play an important role on runoff. The quantity of runoff and sediment becomes a function of the infiltration rate and transmission (percolation) rate of water into and through the soil profile for the various plots, or more broadly, for the heterogeneous soils within a watershed. To cite an example of this heterogeneity of soils among experimental plots, the sediment loss of nitrogen and phosphorus for the spring applied 200 t/ha is inconsistent in comparison to all other treatments. One of the experimental plots associated with the 200 t/ha treatment has a complex slope (surface topography) which runs in two directions and is more strongly sloping than any other plot in the experiment. Due to slope complexity, many of the corn rows ran up and down the slope. Since runoff and erosion is a function of slope, one would expect an increase in nutrient loss with an increase in slope gradient. This single runoff event on the aforementioned plot accounted for 83 and 70% of the total nitrogen and total phosphorus loss, respectively, in sediment on an annual basis. This data should not be ignored or discarded as too complex. It serves to illustrate the kind of results that can be expected in a watershed of varying topography and soil types.

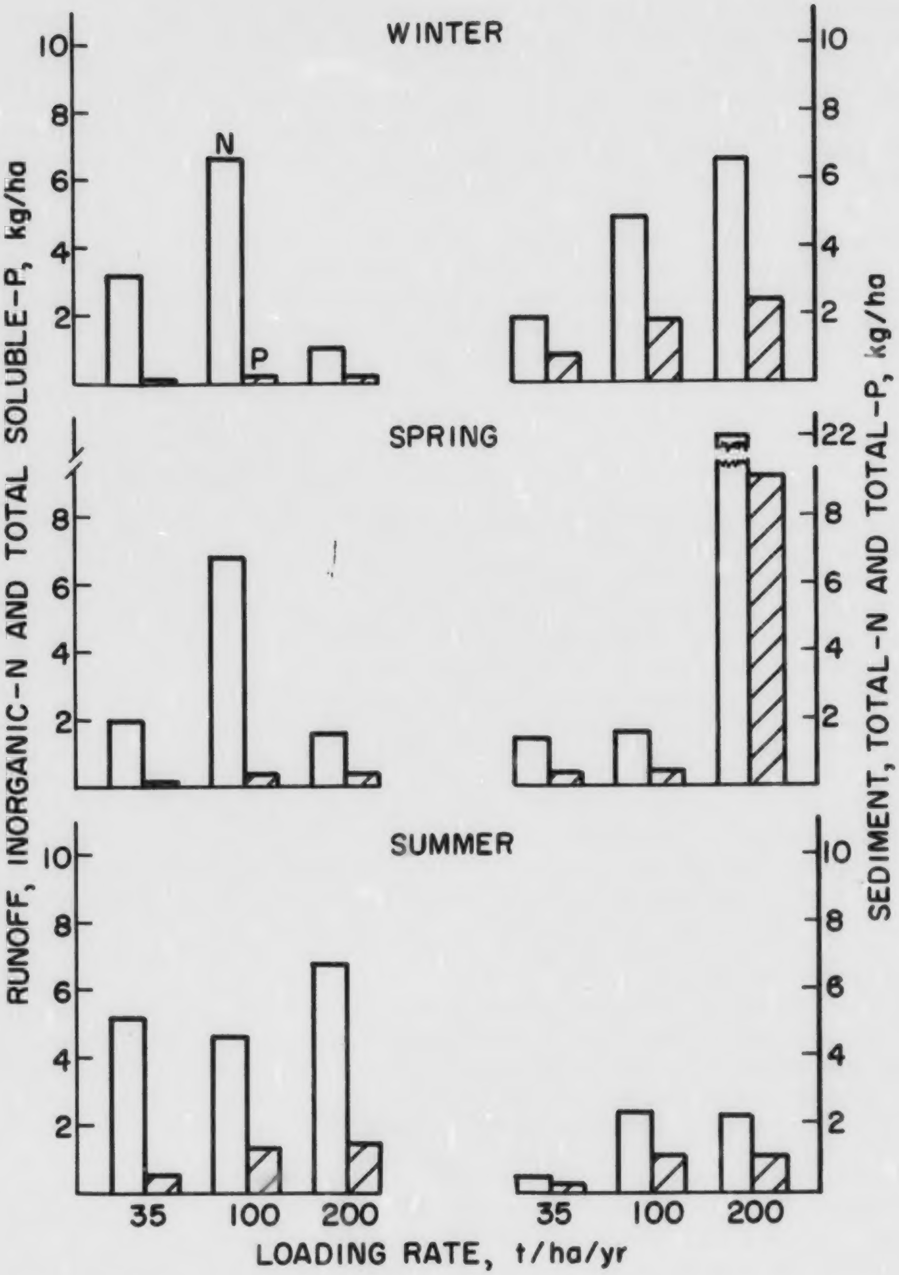


Figure 8. Nitrogen and phosphorus losses from Hurricane Agnes (17.4 cm) with respect to loading rate and time of manure application. 6/26/72.

In general, the nutrient discharges in sediment was significantly lower for the summer application. The mulching effect (reduction of soil exposure) of manure lying on the surface was efficient in reducing soil loss.

August, 1972 - Nutrient losses during an intense rainstorm on August 8, 1972 is presented in Figure 9. The rainstorm delivered 6.8 cm of water of which 6.4 cm fell in one hour. According to U.S. Weather Bureau Standards (72) for short duration storms (less than 2 hrs), this rainfall event was classified as excessive with a probability of 1 in 50 years. Excessive, for short duration storms of 2 hours or less, is defined as:

$$A = [t + 20 \times 2.54]/100$$

where A = accumulated depth of rainfall in time t

t = time or duration of storm.

For any event where t = 60 min, 'A' must be greater than or equal to 2.03 cm in order to be classified as excessive.

When this event occurred, the corn crop was at maximum height and nearly fully matured. With such a high intensity rainfall one would expect severe erosion. Referral to Table 5 shows that the average runoff was considerably less than during the previous winters snowmelt and the spring hurricane. The presence of an almost complete canopy of corn over the soil surface was responsible for reducing the kinetic energy of rainfall impact. The presence of vegetative cover is extremely important in protecting the soil against erosion.

The nutrient losses as illustrated in Figure 9 are approximately an order of magnitude lower than the two previous runoff events.

Statistical analysis of these data show that no real differences between rate and timing of application exist for nitrogen in surface water and nitrogen and phosphorus in sediment. Phosphorus discharges in surface water, although small in magnitude, was significantly higher for the summer application, owing to the fact that exposure of manure on the soil surface at the higher rate resulted in a greater delivery of phosphorus.

The soil management variable influenced total nutrient losses in surface runoff but had no significant affect on sediment losses. On the average, poor soil management resulted in a 2 and 4 fold increase for nitrogen and phosphorus, respectively, in surface water in comparison to well managed soils.

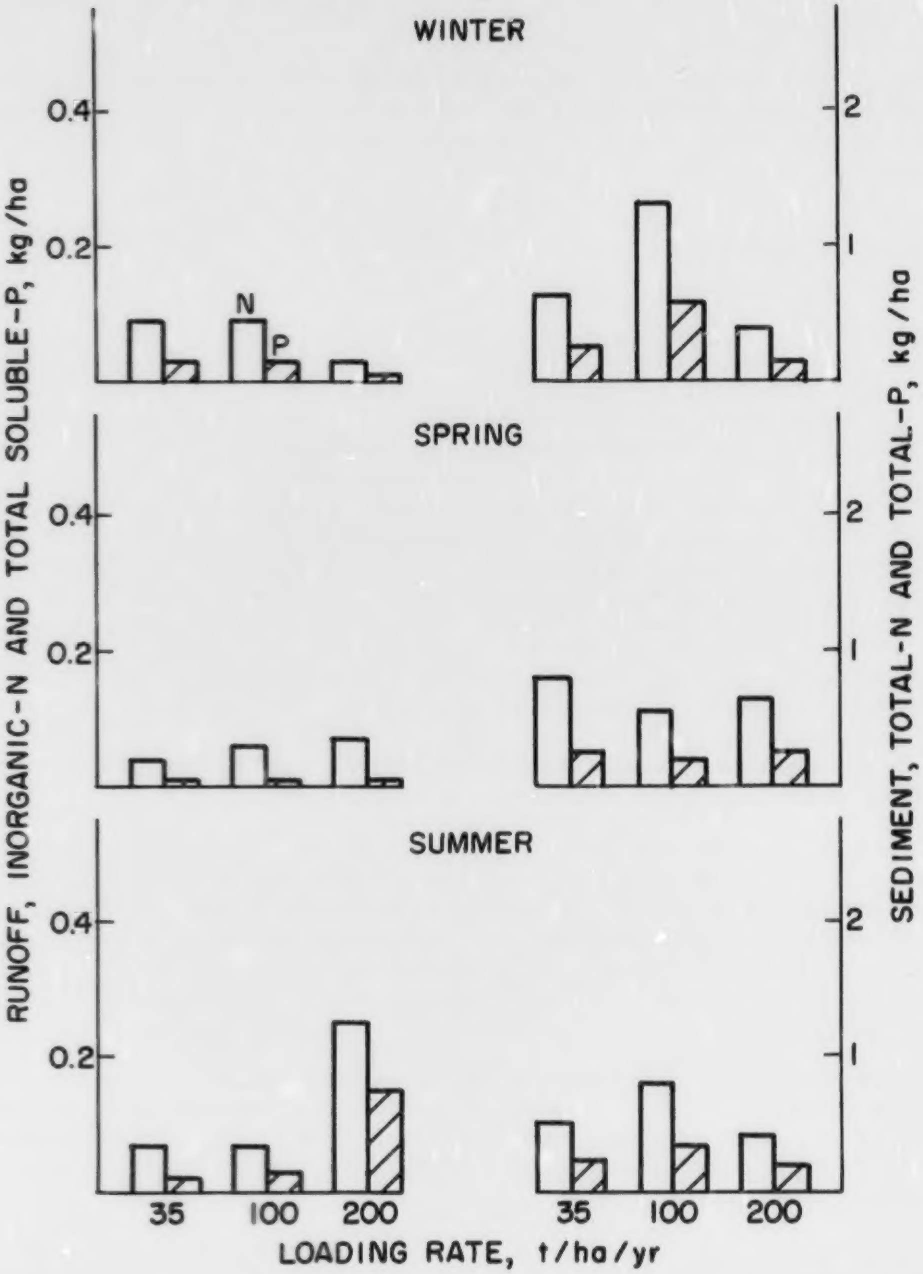


Figure 9. Nitrogen and phosphorus losses from an intense rainstorm with respect to loading rate and time of manure application. 8/27/72.

December, 1972 - The last event selected for 1972 occurred in December and resulted from a five day rainfall, totaling 3.8 cm, on non-snow covered soil. Of special interest was the response of the time lapsed since disposal and the resultant nutrient discharges. The event occurred on December 7, 1972 almost one year since the previous winter disposal and 8 and 7 months after the spring and summer applications, respectively. The manure from the summer application still remained on the soil surface. Total nutrient losses (Figure 10) are quite small and nearly approximate the discharges resulting from the intense August storm (Figure 9). More specifically, the summer application resulted in significantly greater discharges of nitrogen and phosphorus than its counterparts. The exposure of soluble nutrients on the soil surface versus the plowing down of manure was still showing an influence at this later date.

Phosphorus losses in runoff were lower for the minimum rate and showed no real difference between the two higher rates. The same was true of nitrogen in runoff at the lower rate, but again the 100 t/ha application, regardless of the time of application yielded greater nitrogen losses (Figure 10). The absence of underdrainage, particular to this treatment, is influential in increasing runoff. With increased runoff and a reduction in the leaching of soluble nitrogen, because of the lack of tile drainage, increased discharge resulted.

The resultant sediment losses of these two nutrients showed that there are insignificant differences with regard to the overall rates of application. The interaction between time of application and the rate applied showed that the spring applied 200 t/ha treatment had the greater discharge of nitrogen and phosphorus. The physical characteristics of one of the plots associated with this treatment (slope gradient) has previously been mentioned in the discussion dealing with Hurricane Agnes (Figure 8). The same principle is operating in this case. In reality, the relative differences are small with maximum losses never exceeding 0.5 kg/ha.

The soil management variable was influential for this runoff event. By this time, the corn had been harvested. Poorly managed soils were void of plant residue (corn harvested for silage - only stubble remains). The well managed treatments contained a good cover of plant residues (corn harvested as grain - stover remains) on the soil surface which aided in reducing erosion. Table 7 shows the reduced losses with good soil management practices as averaged over all manure treatments.

At the conclusion of this runoff event, one complete manure treatment cycle had been made. On January 12, 1973, the second winter application

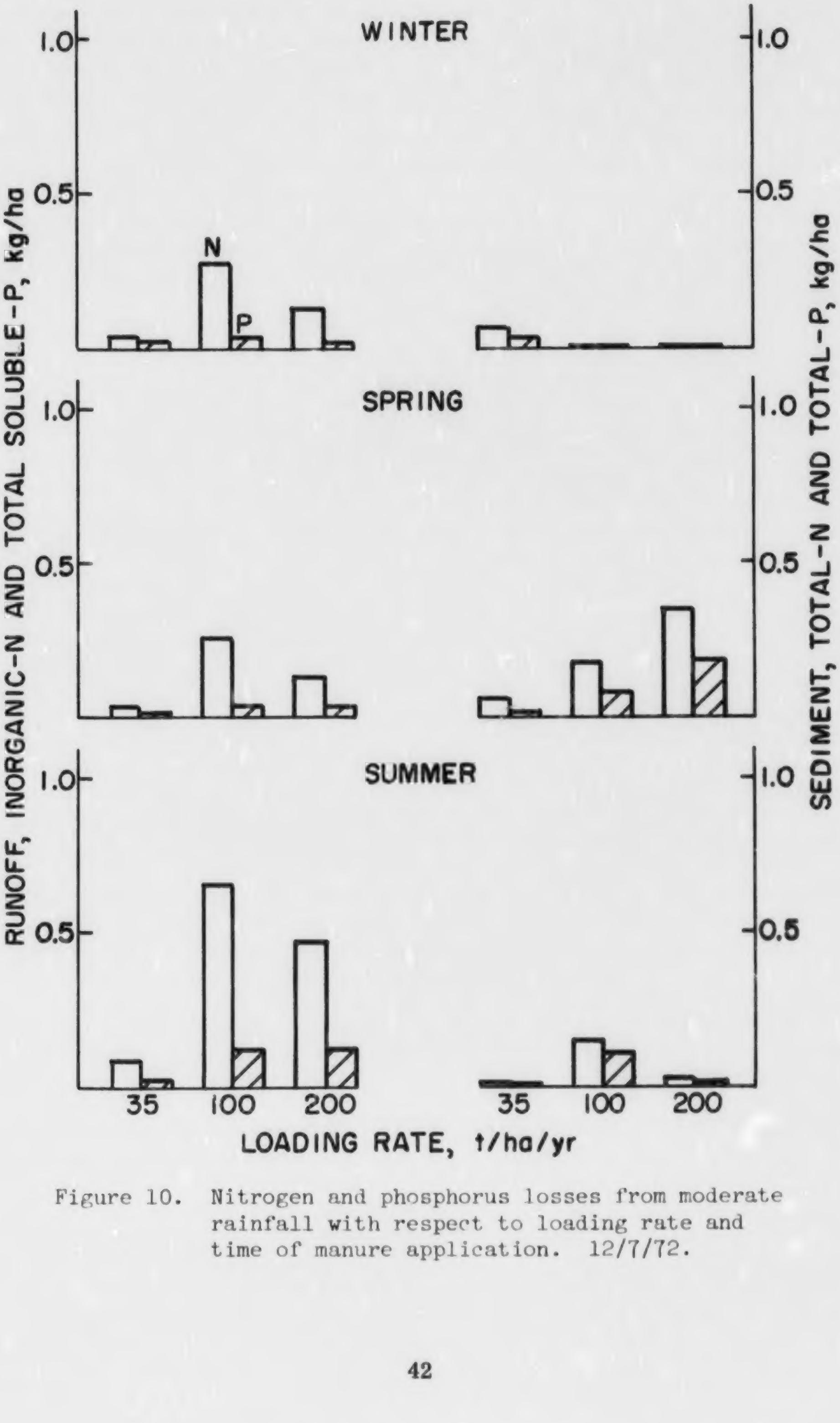


Figure 10. Nitrogen and phosphorus losses from moderate rainfall with respect to loading rate and time of manure application. 12/7/72.

Table 7. THE INFLUENCE OF SOIL MANAGEMENT ON NUTRIENT DISCHARGE DURING WINTER RAINFALL. 12/7/72[a]

Soil mg't	Surface runoff, kg/ha		Sediment, kg/ha	
	N	P	N	P
Good	0.10 a	0.02 a	0.02 a	0.01 a
Poor	0.28 b	0.06 b	0.14 b	0.08 b

[a] Means followed by the same letter are not significantly different @ 5% level.

of manure began and was completed on January 17. At the time of disposal, the soil was frozen to approximately 10 cm with a 2.5 cm snow cover. The beginning of the second cycle affords an opportunity to look at the residual effects of manure from the prior cycle.

March, 1973 - The first runoff event selected for 1973 occurred on March 19 due to an accumulated 6.6 cm of rainfall over a five day period. At this time there was approximately 1 cm of snow cover upon a non-frozen soil. The discharge of nitrogen in surface water for this event (Figure 11) was not significantly greater for the winter application in comparison to the previous applications of last spring and summer. The residual nitrogen from prior applications was great enough to approximate the losses incurred from a very recent winter application. From Figure 11, the range of nitrogen discharge was approximately 0.25 to 1.25 kg/ha.

Phosphorus, on the other hand, displayed a higher discharge in surface water for the winter application because of readily available soluble phosphorus. The residual effects of phosphorus from the first cycle (spring and summer application) was not as influential as nitrogen in supplying soluble material in runoff. Future availability of insoluble phosphorus from manure, like nitrogen, is provided by chemical and biological transformation from the insoluble to the soluble phase. However, unlike inorganic nitrogen, phosphorus is not highly mobile and soil fixation can render much of the soluble portion as unavailable.

The average effect of the rate of application showed no differences with respect to nitrogen but did increase a significant amount for phosphorus as the rate increased.

The sediment contents from this runoff event as influenced by treatment, was not as well defined as the material in surface runoff. In general terms, neither the rate or timing of manure application had any significant influence on nutrient losses. The peak nitrogen and phosphorus losses are noted for the winter applied 100 t/ha and the spring applied 200 t/ha treatments.

The above sediment data for these two isolated treatments is presented in Table 8 for clarification. It is evident from this table that the poorly managed plots associated with these two treatments was responsible for the higher average loss for the rate of application. The well managed soil for the winter and spring treatments contained nitrogen and phosphorus losses in sediment very much in line with the recorded losses for the 35 and 200 t/ha winter rates (Figure 11). In essence, improved soil structure through careful soil management is extremely beneficial.

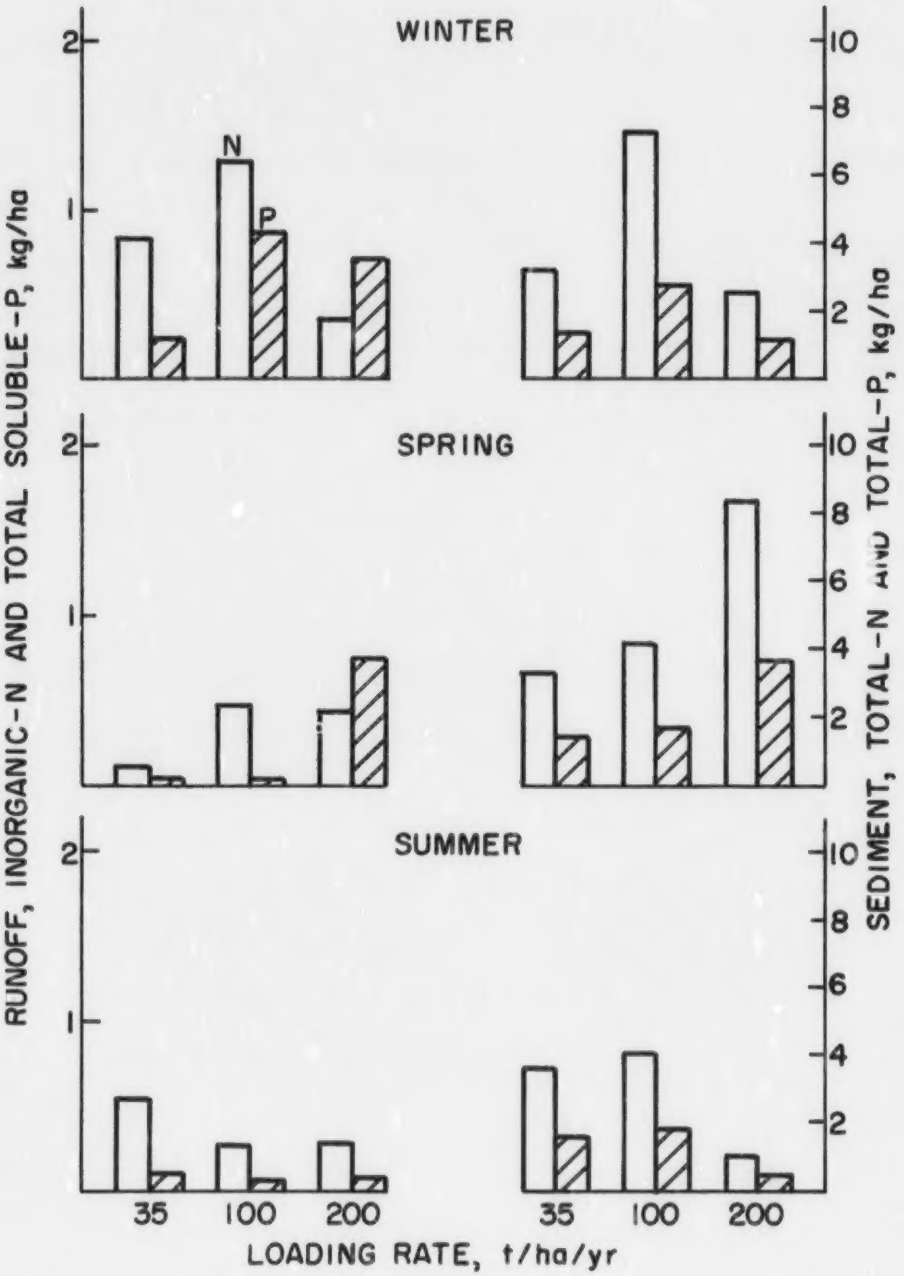


Figure 11. Nitrogen and phosphorus losses from winter rainfall (6.6 cm) with respect to loading rate and time of manure application. 3/19/73.

Table 8. INFLUENCE OF SOIL MANAGEMENT ON THE DISCHARGE OF TOTAL NITROGEN AND TOTAL PHOSPHORUS IN SEDIMENT FOR TWO ISOLATED TREATMENTS. 3/19/73[a]

Time of applic.	Loading rate, t/ha	Soil mg't	Sediment discharge, kg/ha N	P
Winter	100	Good	1.8 a	0.8 a
		Poor	12.8 b	4.8 b
Spring	200	Good	3.4 a	1.6 a
		Poor	13.5 b	5.8 b

[a] Values followed by the same letter are not significant @ 5% level.

Although the 200 t/ha rates appeared on experimental plots that contain a tile line for underdrainage, the poorly managed soil for the spring application is inherently more erosive because of its more complex slope in addition to having a poor soil structure due to management. The well managed plot associated with this treatment (Table 8) displayed nutrient losses in sediment parallel with other spring treatments (Figure 11).

The soil management variable as averaged over all rates and time of application for this event, unlike many of the others, had no significant influence on surface runoff discharges of nitrogen and phosphorus. Sediment losses of these two nutrients, however, were strongly influenced by soil management, with a 150% and 140% reduction in nitrogen and phosphorus, respectively, for good management.

April, 1973 - The runoff event of April 6, 1973 (Figure 12) occurred just prior to the spring application and affords another look at runoff quality after winter spreading and the effects of residual nitrogen and phosphorus from applications made prior to the last growing season. Runoff began on April 1 activated by 2.8 cm. of rainfall. Rainfall and runoff lasted 6 days with a total of 8.0 cm of precipitation. Total average runoff approximated the previous selected runoff event, but soil loss was substantially lower, even though precipitation was 1.4 cm greater (Tables 4 and 5). The combination of these two runoff events accounted for 77% of the annual runoff and 91% of the annual soil loss for 1973.

The residual effects of nitrogen in surface water from previous applications (spring and summer of 1972) was still making an important contribution to nitrogen discharges. Statistical comparisons show that overall nitrogen losses are significantly lower for the winter application in comparison to summer applications but are equivalent to discharges resulting from spring applications. The major difference between the spring and summer treatments was that the manure applied in the spring had been plowed down while summer applied treatments contained manure exposed on the soil surface. Surface exposure of manure would enhance nutrient removal to a greater extent than manure that had been plowed down. This is especially evident with the greater phosphorus discharges for the summer application in comparison to those made in the spring.

Phosphorus discharges in surface water effluent were considerably higher for the very recent winter application, which was exposed on the soil surface at the time of this event. The initial output of phosphorus is high for freshly spread manure. Total soluble phosphorus contents of dairy manure for this winter application was 0.30%. This soluble fraction accounted for 60% of the total phosphorus in

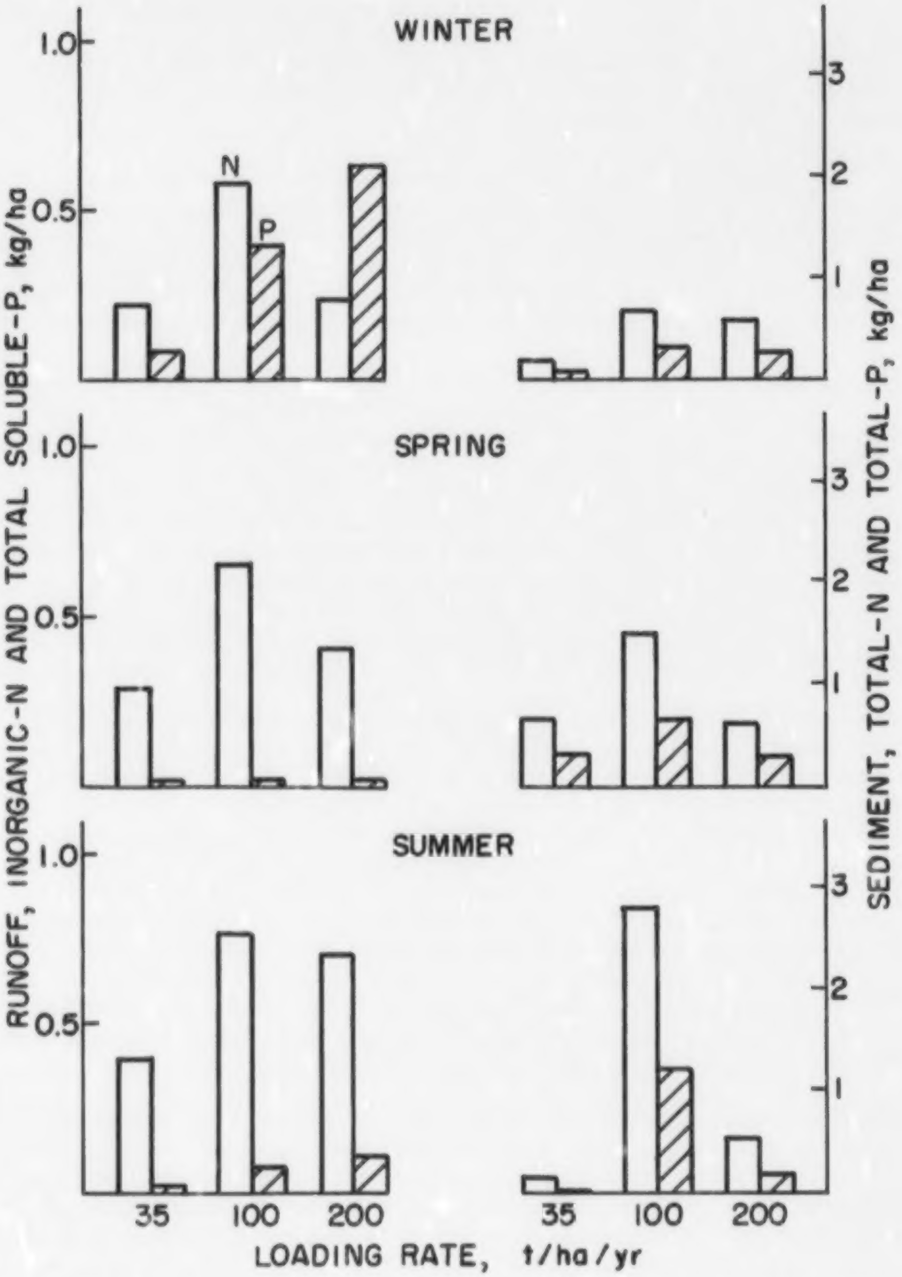


Figure 12. Nitrogen and phosphorus losses from spring rainfall (8.0 cm) with respect to loading rate and time of manure application. 4/6/73.

the applied manure (Table A8, Appendix). Prior leaching and soil fixation of phosphorus accounted for the lower discharge of phosphorus for the previous year's spring and summer application.

Residual nitrogen in manure played an important role in water quality at a later date. Residual phosphorus, on the other hand, is less significant.

Average sediment discharges of these two elements with regard to the time of application were essentially the same from a statistical viewpoint. Sediment losses for the runoff event of April 6, 1973 (Figure 12) are plotted against an expanded scale of three-fold in comparison to the prior runoff event of March 19, 1973. Maximum nutrient losses of the latter event approximate the minimum discharge of the former runoff event.

December, 1973 - The remaining spring and summer season was relatively dry, producing only two additional runoff events before July, 1973. There was no recorded runoff from July until the last week in December. The runoff event of December 27, 1973 was selected to further study the magnitude of nutrient losses during the winter. On the whole, this event, as presented in Figure 13, accounted for only 5% of the annual runoff and 3% of annual soil loss (Table 5). From a nutrient loss standpoint this event was inconsequential, but serves to illustrate expected losses from minor snowmelt events accompanied by rainfall (1.2 cm) on a non-frozen soil.

Treatment comparisons for this event are difficult to access since less than 50% of the treatments produced runoff. With no runoff, discharge quantities are recorded as zero.

Runoff occurred two weeks prior to the beginning of the third winter's manure application. Nutrient losses are minor in comparison to previous events. Average nitrogen and phosphorus losses for both runoff and sediment appeared to correlate to the lapsed time since manure disposal (summer > spring > winter).

February, 1974 - The next to the last event (Figure 14) to be discussed, occurred on February 24, 1974 as a result of 1.3 cm of rainfall and associated snowmelt resulting from an accumulation of 1.0 cm. Much like the runoff event of December 27, 1973, nutrient losses were minimal. The winter of 1974, like 1973, did not result in any major

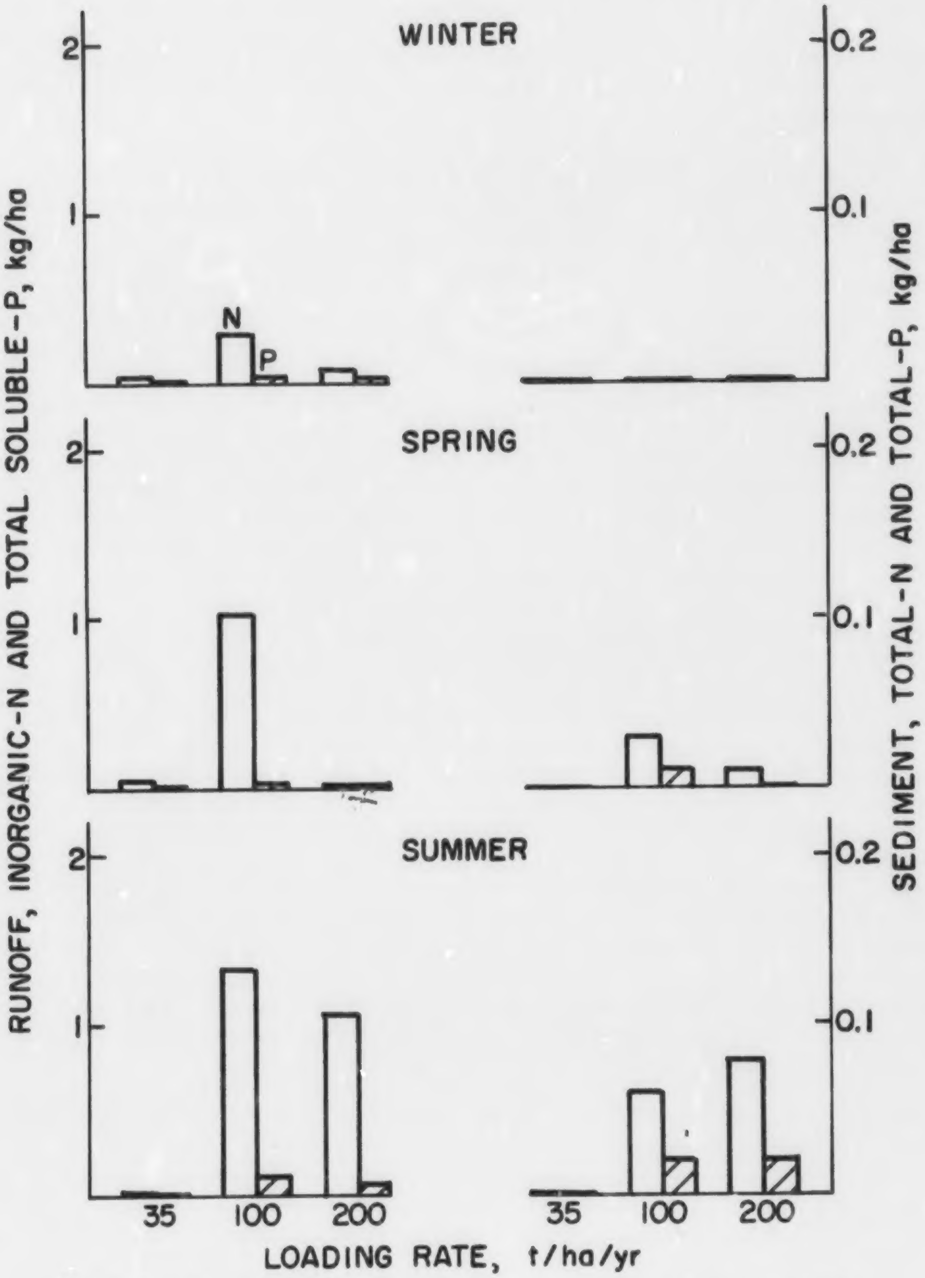


Figure 13. Nitrogen and phosphorus losses from snowmelt with respect to loading rate and time of manure application. 12/27/73.

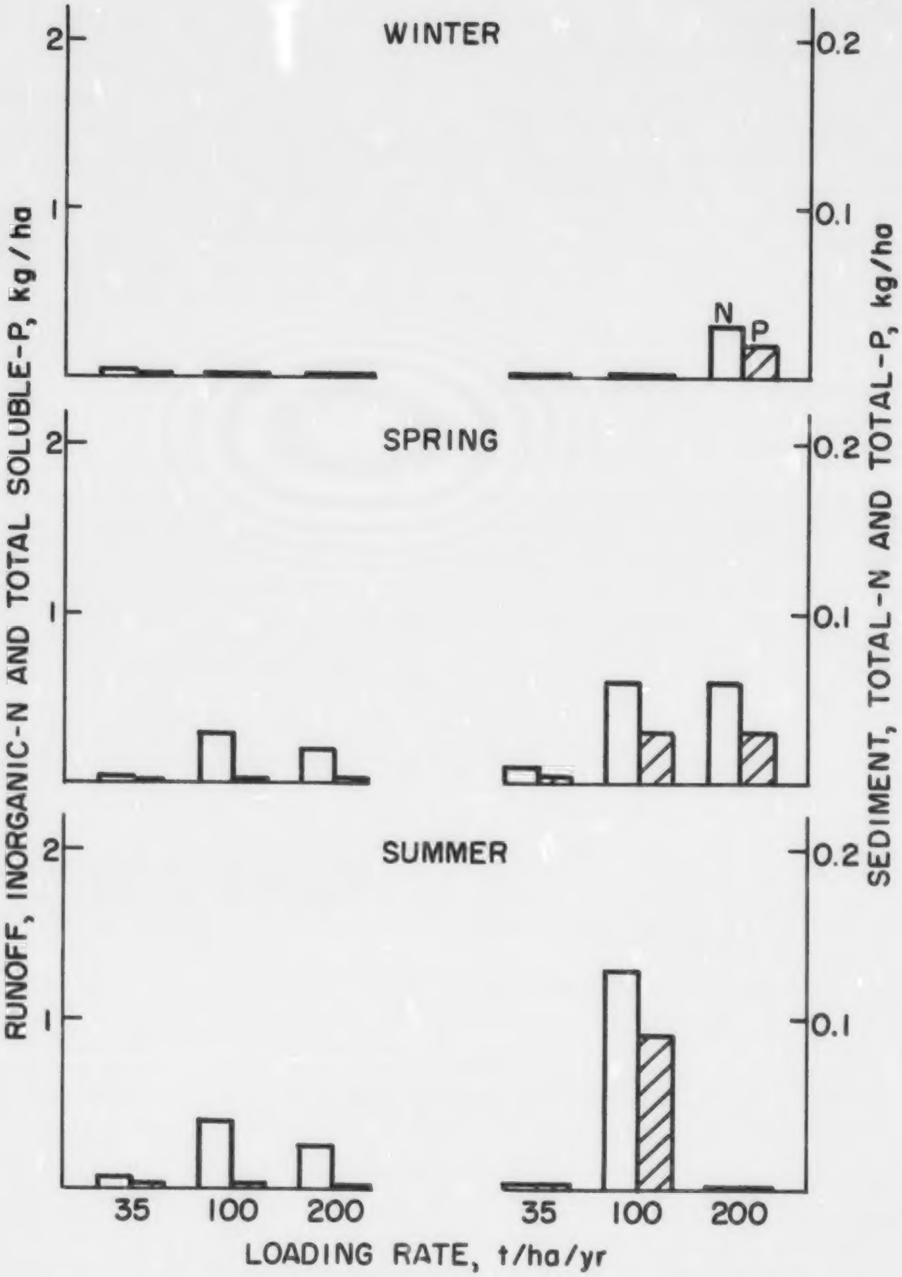


Figure 14. Nitrogen and phosphorus losses from snowmelt and rainfall with respect to loading rate and time of manure application. 2/24/74.

snowmelt events. The presentation of these data will show expected nutrient discharges from snowmelt after a recent winter application (made in mid-January) in contrast to applications made prior to the last growing season.

Runoff occurred on slightly less than 50% of the plots with many treatments having a discharge quantity equal to zero. Runoff was extremely minimal from the winter applied treatments and is probably due in part to the recent cover of manure on the soil surface. This mulch would aid in absorption and retention of rainfall or snowmelt. The only runoff produced from the winter treatments were from the poorly managed plots at the minimum and maximum rates of application, accounting for the slight discharges of nitrogen in surface water and both nitrogen and phosphorus in sediment.

In general, residual losses of these two elements from the past spring and summer application contributed more to surface water and sediment discharges than a recent winter application.

June, 1974 - The last runoff event to be discussed occurred on June 11, 1974 twelve days after the summer application was applied on top of growing corn. The past winter and spring applications had been plowed down. Rainfall was intense with 4.6 cm occurring in 75 minutes. According to U.S. Weather Bureau standards for short duration storms (<2 hrs), this rainfall event was classified as excessive, approximating a 1 in 10 year probability. At this time, the corn was approximately 10 cm high.

Nutrient losses in surface runoff as presented in Figure 15 were quite small. Inorganic nitrogen did not exhibit a significant change relative to the rate or timing of manure application. Phosphorus on the other hand showed a small but significant increase in runoff water for the summer application, owing to the very recent addition of manure. Total phosphorus and total nitrogen in sediment did not show itself to be significantly influenced by the timing or rate of application.

Although this event was caused by a fairly intense rainstorm, erosion losses were at a minimum. In comparison, this storm was not as intense as that occurring on August 27, 1972. Total contributing rainfall for the August 1972 storm was 1.5 times greater with the average runoff and soil loss being 3.5 and 2.0 times greater, respectively in comparison to this intense June 1974 storm.

Trends - Diffuse sources of nutrient discharges are difficult to characterize and assess because of the normal variability that is encountered in an agricultural watershed. Although many inconsistencies may appear with nutrient loss measurements from non-point sources,

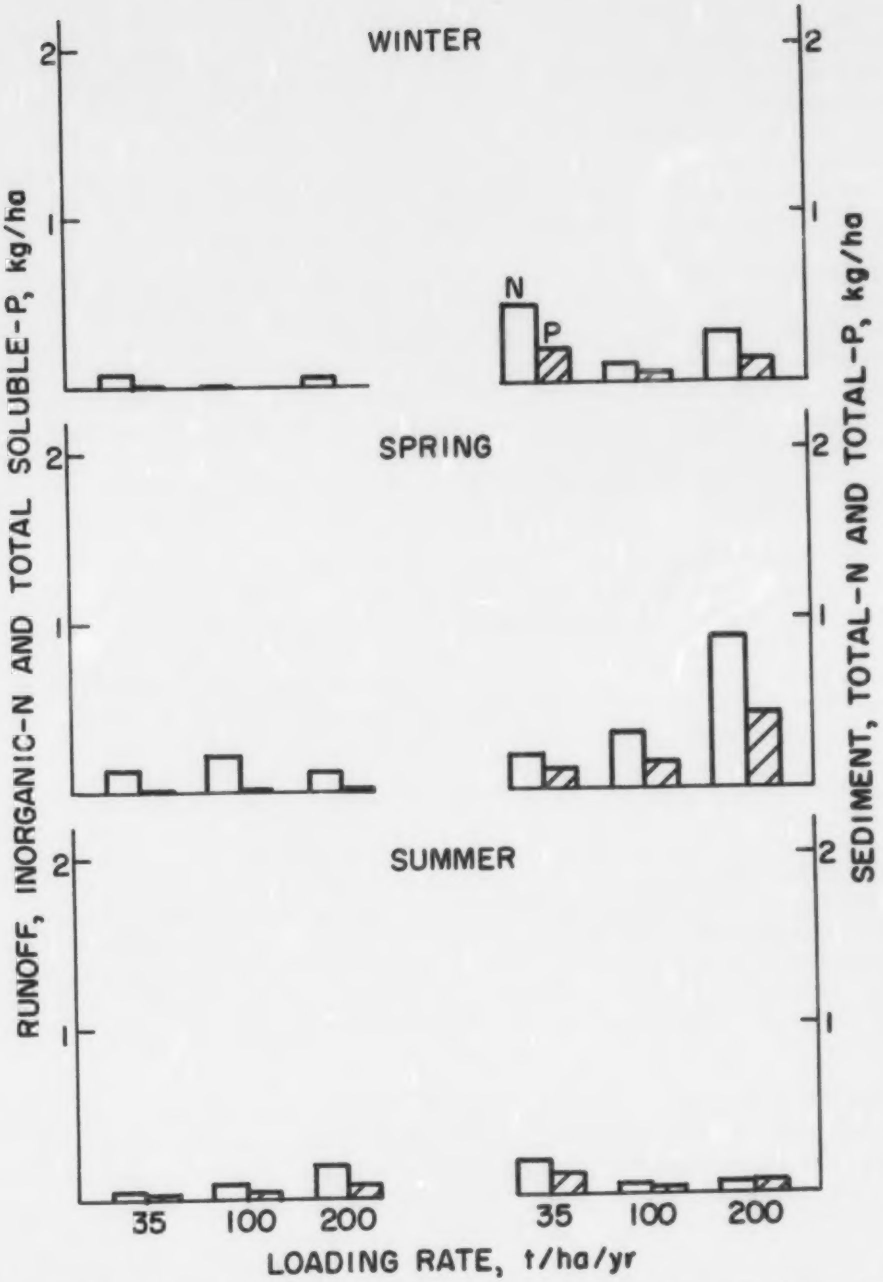


Figure 15. Nitrogen and phosphorus losses from an intense rainfall (4.6 cm in 75 min.) with respect to loading rate and time of manure application. 6/11/74.

many consistent and significant trends are evident.

The runoff event of February 1972 clearly demonstrated that common sense must dictate ones winter disposal activities. High rates of manure loadings over extensive areas, as the result of cleaning out manure storage facilities, as this experiment has tempted to simulate, during snowmelt activities is inexcusable. Lower loading rates, in the neighborhood of 35 t/ha during non-snow melt periods, has shown nutrient discharges to be within acceptable tolerances when compared to fields receiving no manure (Figure 7).

The soil and vegetative cover on disposal fields are all important. Erratic nutrient discharges, in relation to the rate or time of application, can be encountered because of the influence of soil heterogenity among disposal fields. The hurricane in June of 1972, pointed out that when the soil is saturated, the influence of rate and timing of manure applications is masked by many independent soil variables which strongly influence runoff. The same was true even when soils are not saturated prior to or during a rainstorm, but to a lesser degree.

The importance of vegetative cover during intense rainstorms is clear cut in terms of soil protection and a protective canopy to aid in the reduction of raindrop impact. This was demonstrated as the result of the intense August 1972 and June 1974 rainfalls. Vegetative residues left on the soil surface (good soil management) had also proved to be very beneficial in reducing nutrient discharges on imperfectly drained soils.

The residual nitrogen and phosphorus from previous applications had some influence on nutrient discharge the following year. Reference to the events of March 1973, April 1973, December 1973 and February 1974 showed that residual nitrogen exhibited a greater availability in comparison to residual phosphorus. Future availability of insoluble phosphorus from manure, like nitrogen, is generated by mineralization from the insoluble organic to the soluble inorganic phase. However, unlike inorganic nitrogen, phosphorus is not highly mobile and soil fixation can immobilize much of the soluble inorganic fraction.

A series of correlation and regression coefficients have been calculated for the nine individual treatments (3 disposal periods x 3 application rates) emphasized in this section. Tables 9 and 10 are estimates of these coefficients as a result of the nine selected runoff events.

Table 9. CORRELATION AND LINEAR REGRESSION COEFFICIENTS FOR THE DISCHARGE OF INORGANIC NITROGEN IN SURFACE RUNOFF RESULTING FROM NINE SELECTED EVENTS.

Time of application	Rate, t/ha	Means					
		runoff(X), m^3	N(Y),kg	r[a]	S.E.[b]	a[c]	b[d]
Winter	35	44.8	0.24	0.90	0.19	- .09	.007
	100	80.1	2.46	0.51	5.58	- .71	.040
	200	38.1	0.45	0.25	1.11	.20	.006
Spring	35	40.5	0.13	0.88	0.12	- .08	.005
	100	83.1	0.45	0.89	0.42	- .21	.007
	200	64.5	0.47	0.63	0.85	- .12	.009
Summer	35	63.5	0.46	0.95	0.25	- .15	.010
	100	122.9	0.40	0.91	0.26	- .07	.004
	200	90.0	0.47	0.89	0.54	- .16	.007

[a] Correlation coefficient, $\geq$ .67 P @ .05 for 7 d.f.

[b] Standard error of estimate.

[c] Intercept

[d] Slope

Table 10. CORRELATION AND LINEAR REGRESSION COEFFICIENTS FOR THE DISCHARGE OF TOTAL SOLUBLE PHOSPHORUS IN SURFACE RUNOFF RESULTING FROM NINE SELECTED EVENTS.

Time of application	Rate, t/ha	Means runoff(X),m^3	P(Y),kg	r[a]	S.E.[b]	a[c]	b[d]
Winter	35	44.9	0.04	0.34	0.05	.02	.0003
	100	80.2	0.47	0.44	1.15	-.07	.007
	200	38.1	0.22	0.20	0.46	.13	.002
Spring	35	40.5	0.01	0.97	0.001	-.0002	.0001
	100	83.1	2.01	0.20	6.27	.97	.012
	200	64.5	0.19	0.61	0.34	-.04	.004
Summer	35	63.4	0.83	-0.17	2.44	1.16	.005
	100	122.9	0.08	0.93	0.07	-.05	.001
	200	90.1	0.09	0.79	0.12	-.04	.002

[a] Correlation coefficient, $\geq$ .67 P @ .05 for 7 d.f.

[b] Standard error of estimate.

[c] Intercept.

[d] Slope

The relationship between runoff and nitrogen discharge (Table 9) showed a significant correlation (r) in 6 out of 9 treatments. Runoff versus phosphorus discharge (Table 10) showed a significant relationship in only one-third of the treatments. Even though the description of a correlation remains highly contingent upon what is being assessed, it is still useful to have some consistency of terminology in describing the magnitude of the coefficient itself. Guilford (28) offers a rough guide:

r = < .20 slight; almost neglible relationships
r = .20-.40 low correlation; definite but small relationship.
r = .40-.70 moderate correlation; substantial relationship
r = .70-.90 high correlation; marked relationship
r = > .90 very high correlation; dependable relationship.

Perhaps a more important indication of the strength of these relationships would be to consider the standard error of the estimate (S.E.) or the standard deviation of Y holding X constant. In most instances, the standard error exceeds the mean of Y, strongly indicating a large degree of variation.

The rate of manure application has always been of interest to the researcher when dealing with nutrient losses. Figures 16 and 17 illustrate the relationship between nutrient discharge and quantity of runoff for nitrogen and phosphorus at each rate of application over the nine runoff events. It is obvious from these figures that a strong relationship is non-existent. The data points are scattered considerably because of varying soil surface conditions, which influence runoff, and a large amount of variability in nutrient concentration, depending on the time of the year runoff occurs in relation to the time lapsed since manure disposal. Tables A11 - A14 of the Appendix denotes runoff and nutrient concentrations for the presented data. Average concentrations are determined only from plots having runoff whereas the quantity of nutrient discharge takes zero discharge into account.

It is not within the scope of this experiment to construct computer simulation models for nutrient discharge from manured landscapes. Conceivably, models could be developed based on these findings plus a well thought through conception of the necessary independent parameters influencing nutrient removal.

Winter Disposal -

There has been much controversy in the past about the land application of manure during the winter season. Many feel that nutrient loadings from winter applied manure will be greater than from applications made during the spring, summer or fall seasons.

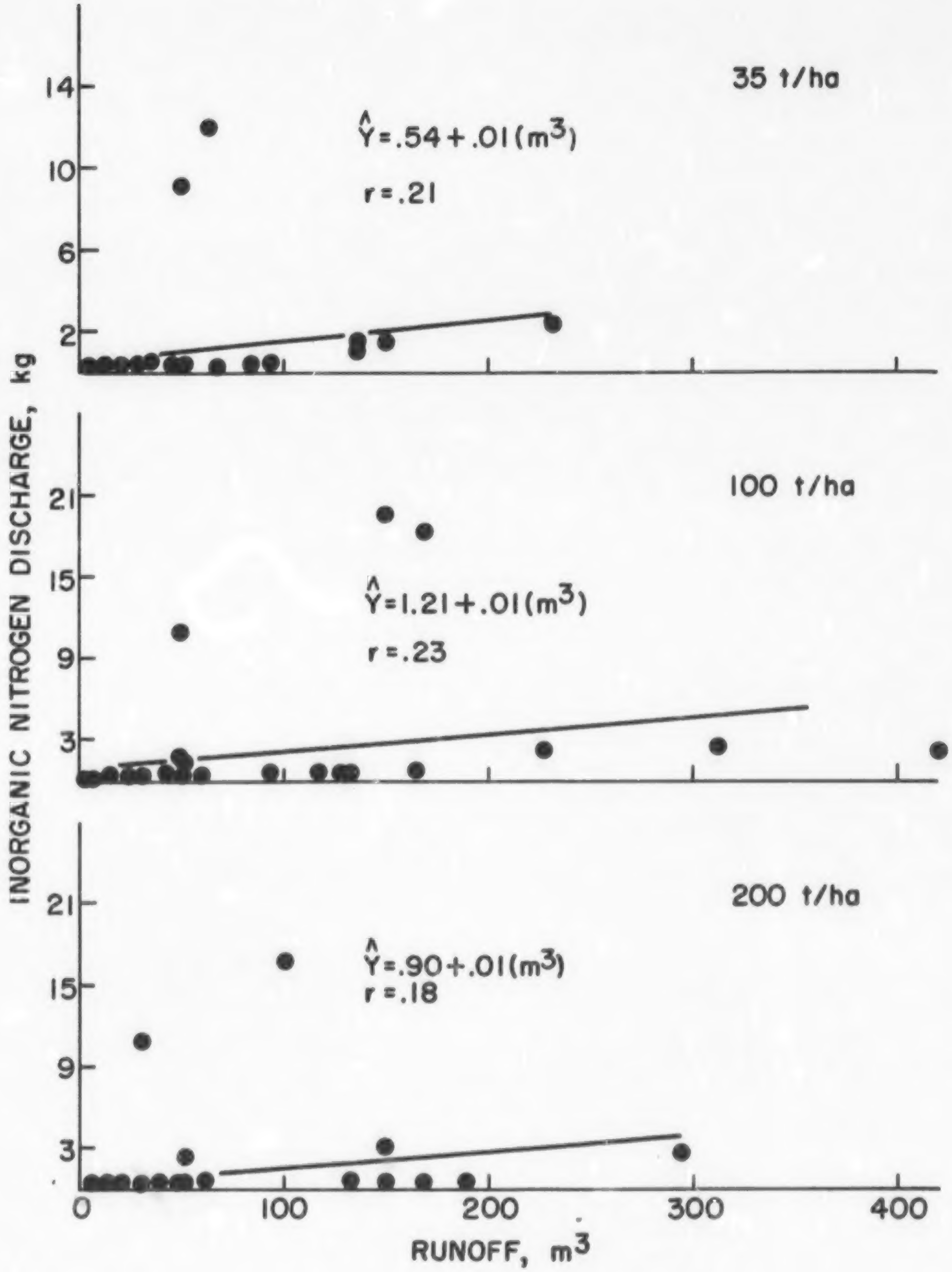


Figure 16. Discharge of inorganic-N in runoff for nine selected events with respect to rate of manure application.

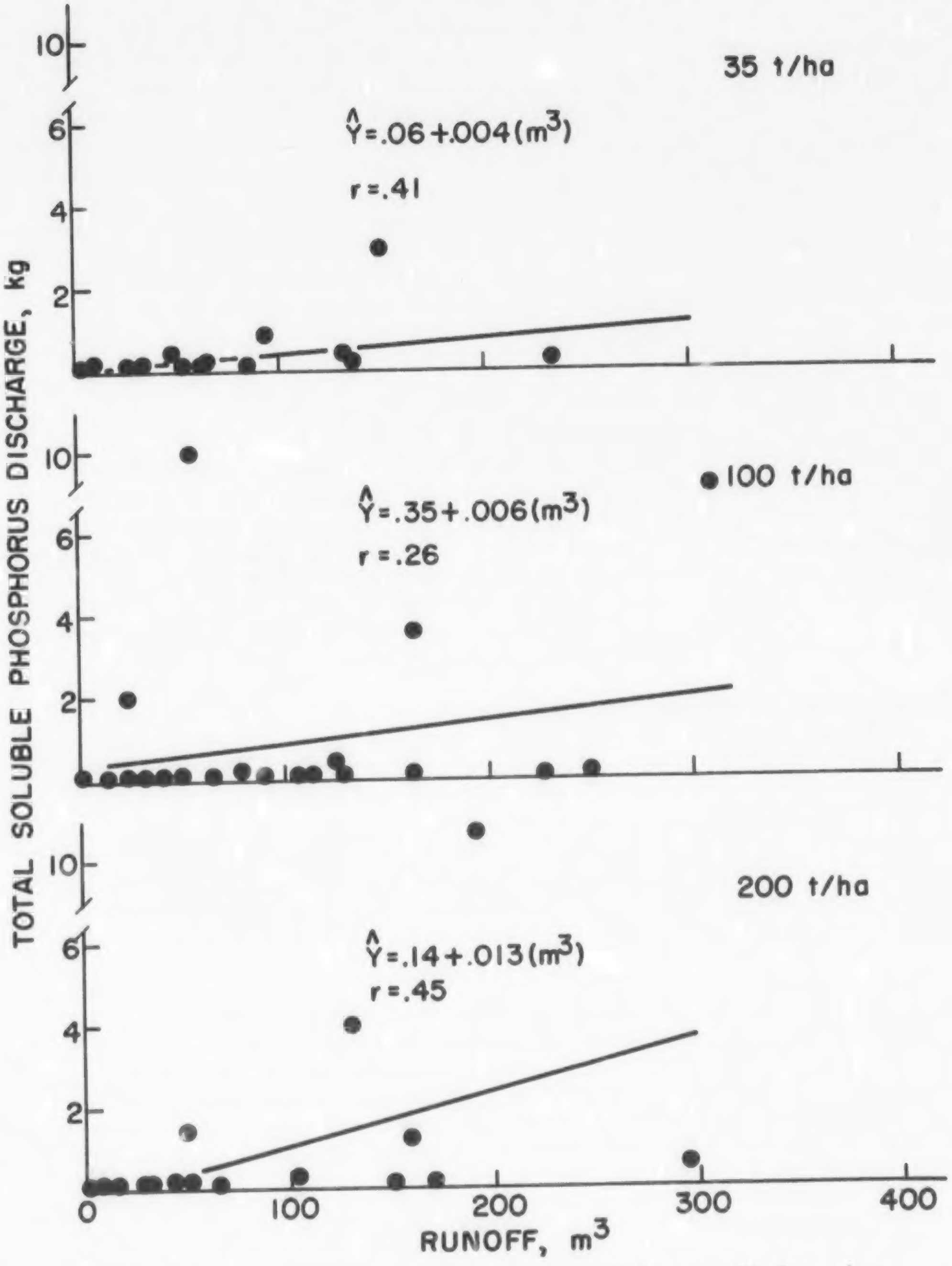


Figure 17. Discharge of total soluble-P in runoff for nine selected events with respect to rate of manure application.

In previous discussions, annual losses of nitrogen and phosphorus over a two year period from winter applications were compared to those losses from spring and summer applications. A brief summarization of the aforementioned data would be helpful to refresh the readers memory. The cumulative losses of nitrogen and phosphorus during 1972 and 1973 in sediment from winter applications were not statistically greater than losses from spring and summer applications. With respect to soluble nitrogen in surface water, there was a significant increase from winter applications over spring and summer disposal in 1972, but any real differences in 1973 were non-existent. In fact, during 1973, losses of inorganic nitrogen from winter applied plots were equal to the loadings from spring applications and somewhat less than those incurred from fields receiving a summer application. However, soluble phosphorus loadings in surface runoff were significantly greater from winter applied treatments, for both 1972 and 1973, in contrast to spring and summer applications.

The following discussion will center on the losses of nitrogen and phosphorus in surface water and sediment associated with various rates of applied manure during the winter for three consecutive years. The main emphasis will be placed on the rate of application and the variation that can be expected from one year to the next. The field experiment actually began in February 1972. January 1 was selected as a starting point, as a matter of convenience, and April 1 for cessation of winter activity.

A comparison of several weather parameters, as summed over the months of January, February and March, for a three year period are given in Table 11. From these data, the winter of 1972 appears to be fairly typical of expected precipitation and snowfall, whereas 1973 and 1974 are somewhat below average, especially for snowfall. The striking difference between years is in the number of days the soil was frozen and the number of days there was a cover of snow over the soil surface. During 1972, the soil was frozen for 62 days during the three month period in comparison to 12 days for 1973 and zero days for 1974. These soil temperatures were taken at the weather station on the farm at a 10 cm depth under sod. A dense sod cover would tend to insulate the soil to a greater degree than would corn stubble, as was present on the experimental plots. The reported number of days in which the soil was actually frozen may be an underestimate. In addition, the soil surface could be frozen although the 10 cm depth may be above freezing. Nevertheless, the number of days of frozen soil under sod at a 10 cm depth may be meaningful in relative comparisons of the three years.

Table 11. COMPARISON OF SEVERAL WEATHER PARAMETERS FOR A THREE YEAR PERIOD. SUM OF JANUARY, FEBRUARY AND MARCH.

	1972		1973		1974	
Total precip, cm	17.5	(+ 0.6)[a]	15.9	(- 1.0)	15.4	(- 1.5)
Snowfall, cm	135	(+ 16)	35	(- 83)	80	(-38)
Frozen soil, days[b]	62		12		0	
Snow cover, days	75		39		64	

[a] Deviation from 14 and 24 year means for precipitation and snowfall, respectively.

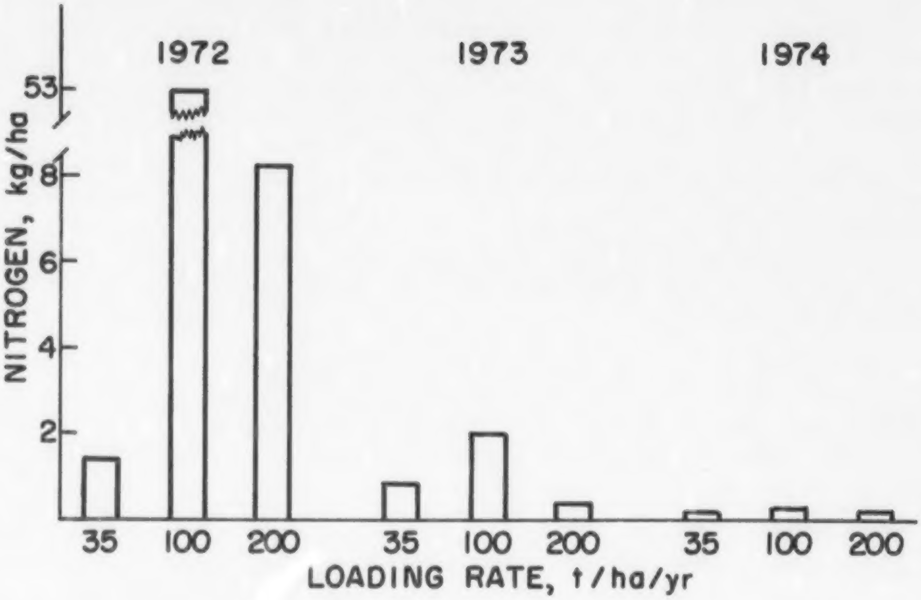
[b] Average daily soil temperature = 0°C at the 10 cm depth under sod.

The cumulative losses of nitrogen and phosphorus in surface runoff from January 1 to April 1 for 1972, 1973 and 1974 are given in Figure 18. There is a marked increase in nutrient losses in 1972 over those occurring in 1973 and 1974. Statistical evaluation of these data have shown these differences to be meaningful. For both nitrogen and phosphorus, nutrient losses between 1973 and 1974 were not significantly different with regard to the year and rate of application.

The greater losses incurred in the winter of 1972 in comparison to 1973 and 1974 is due to a complex series of circumstances. Explanation of these circumstances existing in 1972 is part fact and part speculation. The factual portion deals with the weather conditions existing at the time of disposal. Figure 18 shows the tremendous increased loss of nitrogen and phosphorus associated with the 100 metric ton/ha rate. The 35 and 200 t/ha rate were applied on frozen soil being void of a snow cover. Almost immediately, 48 cm of snowfall had covered the manure, thus delaying the disposal of the 100 t/ha rate for almost two weeks. When the snow had thawed enough, the 100 t/ha rate was applied on 7.5-10 cm of dense melting snow over frozen soil; a disposal condition exemplifying the worst possible manure management practice, but allowing for collection of data under extreme winter conditions.

The first snow melt event occuring after the disposal of the 100 t/ha rate accounted for 72% and 88% of the annual loss of nitrogen and phosphorus, respectively, in surface runoff for this treatment. The poor soil management plot associated with this rate had approximately 3 times the nitrogen discharge and 2 times the phosphorus discharge in comparison to the well managed plot. The excessive nutrient losses associated with this particular treatment was not a reflection of the rate of application, but rather a direct influence of the weather and soil surface conditions present at the time of disposal. For further analysis of this runoff event, refer to the section dealing with selected runoff events. If it were not for this severe disposal condition, it would be safe to speculate that the loss of nitrogen and phosphorus from the 100 t/ha rate would at least approximate the losses resulting from the 200 t/ha application. It is highly unlikely that it is a common practice for dairy farmers to spread moderately high rates of manure over extensive areas consisting of melting snow overlying frozen soil.

The speculative portion of why nutrient losses during 1972 were greater than 1973 and 1974 is based on the tabulated data of Table 11. It appears that January to March of 1972 was fairly typical of the average precipitation and snowfall than can be expected.



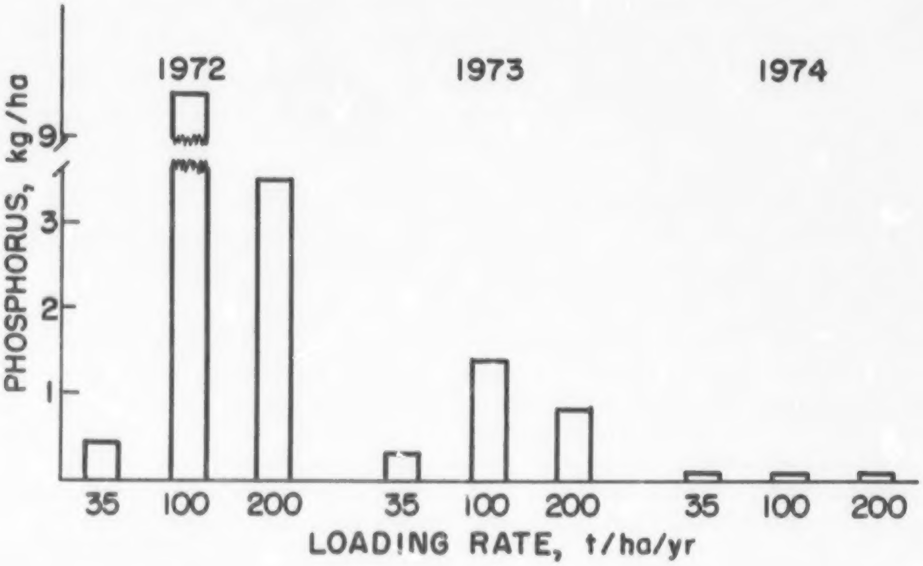


Figure 18. Three year comparison of inorganic nitrogen and total soluble phosphorus discharge in surface runoff due to winter disposal. Cumulative losses are from January 1-April 1.

During the same time period in 1973 and 1974, precipitation, and especially snowfall, deviated below what is considered average. In addition, 1972 had a much greater number of days in which the soil was frozen. With a greater amount of precipitation and occuring days in which the soil remains frozen (1972) one would expect a greater amount of runoff and subsequent nutrient losses.

For modest rates of application (35 t/ha), nutrient loss differences with respect to year were not significantly different for either nitrogen and phosphorus in surface water effluent. This low rate of application may well fall into the acceptable range, when standards are established, for nutrient loadings even in the severest of winters.

The discharge of sediment nitrogen and phosphorus as illustrated in Figure 19 clearly shows a significant rise in nutrient loadings during 1973 over 1972 and 1974. This is the reverse of what occurred with respect to nutrient contents in surface water effluents. That is, nitrogen and phosphorus loadings from surface water was significantly higher in 1972 in comparison to the other years. The lack of correlation between surface water and sediment loadings with respect to year is evident when comparing Figures 18 and 19.

It was postulated that surface water loading was greatest during 1972 because of the more nearly normal amount of precipitation as well as a greater number of days when the soil was frozen. With this being the case, one would expect more runoff. When dealing with sediment discharges, although a function of runoff, the condition of the soil surface is all important. With a given amount of precipitation, sediment yields would be greatest on an exposed surface as compared to an unexposed surface for obvious reasons.

Referring back to Table 11, the 1973 winter had the lowest number of days in which the soil was covered with snow. In theory, soil protection from rainfall impact during winter rains was lower for 1973 in comparison to 1972 and 1974.

The greatest amount of sediment discharged in 1973 occurred from a runoff event lasting 3 days (March 17-19) as a result of 6.6 cm of precipitation over a 5 day period, mostly in the form of rain. At the onset of runoff, the soil was without snow cover. The resultant sediment yield from this event contributed greatly to the cumulative three months loss. In fact, the sediment yield from this runoff event under snow free soil was greater than the sediment losses experienced during the snow melt event of 1972 when manure was spread on top of melting snow. Snow cover in itself forms a barrier to reduce soil erosiveness. A complete discussion of the

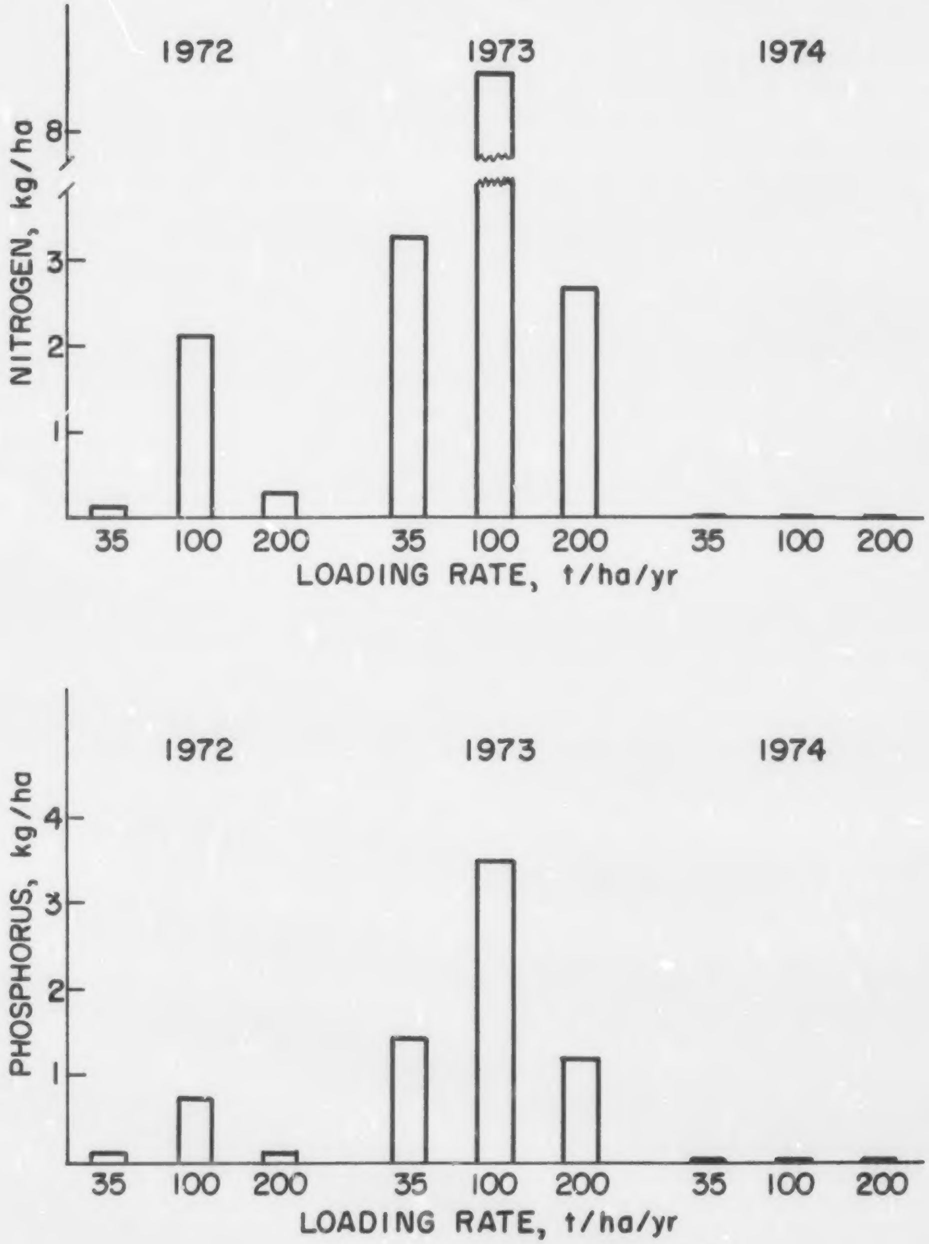


Figure 19. Three year comparison of total nitrogen and total phosphorus discharge in sediment due to winter disposal. Cumulative losses are from January 1-April 1.

aforementioned runoff events can be found in the section dealing with selected runoff events.

The nitrogen and phosphorus discharges as it relates to the loading rate of manure (Figure 19) were not significantly different in 1972 and 1974. The 100 t/ha loading rate during the winter of 1973 yielded a significantly greater amount of nitrogen and phophorus in comparison to the 35 and 200 t/ha rates. It has been mentioned before that the plots containing the 100 t/ha rate do not contain a drain tile and runoff losses may be biased upward.

Nutrient Concentrations -

Total nutrient delivery, a function of runoff volume and nutrient concentration, should be used as the criteria in developing management schemes for land disposal. Average nutrient concentrations, although complex to evaluate, can be used as an additional tool in evaluating land treatments if one accepts and understands the tremendous amount of variability that will be encountered from one drainage event to the next. In addition, frequency distributions of these nutrient contributions can be used in part to compare the relative behavior of several treatments under given conditions.

The following discussion will deal with nitrogen and phosphorus concentrations in drainage water from both surface runoff and tile effluent. The liquid fraction was chosen because of the more thorough understanding and already established environmental standards for potable water, especially for ammonium and nitrate nitrogen (18).

Surface runoff - Calculations of mean nitrogen and phosphorus concentrations and associated variability have been made for two complete manure application cycles (1972, 1973). The third cycle is presently underway. Tables 12 through 15 present these nutrient concentrations.

Ammoniacal nitrogen - The most variable nutrient constituent in runoff was ammoniacal nitrogen (Table 12). The greatest mean concentrations were associated with the winter 100 t/ha and 200 t/ha treatments. The extremely high concentrations at the upper end of the range was responsible for the larger average concentration. Ammonium concentrations of this magnitude (100+ ppm) were not commonplace. Out of 138 observations, only one runoff event had a concentration exceeding 100 ppm for the 200 t/ha rate and two observations out of 164 occurring for the 100 t/ha rate (Figure 20). These three outlying observations all occurred from winter disposal (Figure 21), at the two higher rates of application, as a result of a snow melt event of February 1972. This dairy manure, having 20-25% of its total nitrogen in the form of ammonium (Tables A7 and A8, Appendix) at the time

Table 12. AMMONIUM NITROGEN CONCENTRATIONS IN SURFACE RUNOFF OVER A TWO YEAR PERIOD. 1972, 1973.

Time of applic	Rate, t/ha	Obs	Mean, ppm	Standard deviation	Coeff of variation %	Range
Winter	35	91	1.07	3.03	283	.004 - 20.3
	100	36	8.24	26.22	318	.010 - 115.5
	200	47	4.49	21.21	472	.010 - 144.3
Spring	35	104	0.29	1.01	345	.010 - 9.8
	100	68	0.30	1.05	354	.001 - 8.2
	200	50	1.28	4.01	312	.001 - 22.7
Summer	35	67	0.73	2.34	323	.010 - 14.8
	100	60	0.21	0.22	108	.003 - 0.8
	200	40	0.19	0.34	173	.001 - 1.6

of spreading, can contribute sufficient amounts of NH_4-N to runoff waters if runoff occurs almost immediately after manure application. Lauer, et al.* have demonstrated that ammonia volatilization can occur rapidly after surface application, with ammonia having an approximate half life of 1.9 days at the low rate of application (35 t/ha) and 3.5 days at the higher rate (200 t/ha).

Manure that was applied during the winter of 1972 was either immediately covered with snow before the next runoff event or was applied directly on top of melting snow. These two conditions are not conducive to significant depletions of ammonia by volatilization before becoming solubilized in runoff water.

Ammonium concentrations decreased rapidly with increasing lapsed time since manure disposal. Approximately 80+% of the frequency of ammonium concentrations were less than 1.0 ppm (Figures 20 and 21).

Nitrate nitrogen - Average nitrate nitrogen concentrations in surface runoff (Table 13) were more nearly uniform with respect to treatment than was ammonium nitrogen and exhibited a lesser degree of variation. Unlike ammoniacal nitrogen, nitrate does not comprise a significant portion of the total nitrogen in fresh manure, hence discharge of nitrate into surface runoff is contingent upon the rate of mineralization of the organic fraction and biological and or chemical transformation of existing ammonium nitrogen.

The frequency distribution as illustrated in Figures 22 and 23 showed that roughly 90% of the nitrate nitrogen in runoff was less than the established standard of 10 ppm for potable water. The frequency of nitrate nitrogen exceeding 10 ppm was approximately twice as great for applications of 100 t/ha as compared to its counterparts (Figure 22). The fact that the 100 t/ha rate treatments were not underdrained with tile may very well account for the greater incidence of nitrate nitrogen above 10 ppm. Lack of underdrainage on these imperfectly drained soils may inhibit the downward movement of soluble nitrogen.

Phosphorus - Analytical determinations were made for both soluble inorganic and total soluble phosphorus, the numerical difference being composed of soluble organic phosphorus. Total soluble phosphorus determinations were used in calculations of discharge quantities in previous discussions. Approximately 83% of the total soluble phosphorus was composed of soluble inorganic phosphorus. The two are treated separately in this discussion as a matter of interest.

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*Lauer, D. A., Bouldin, D. R., and Klausner, S. D. Ammonia Volatilization from Dairy Manure Spread on the Soil Surface. Submitted to Journ. Envir. Qual. 1974.

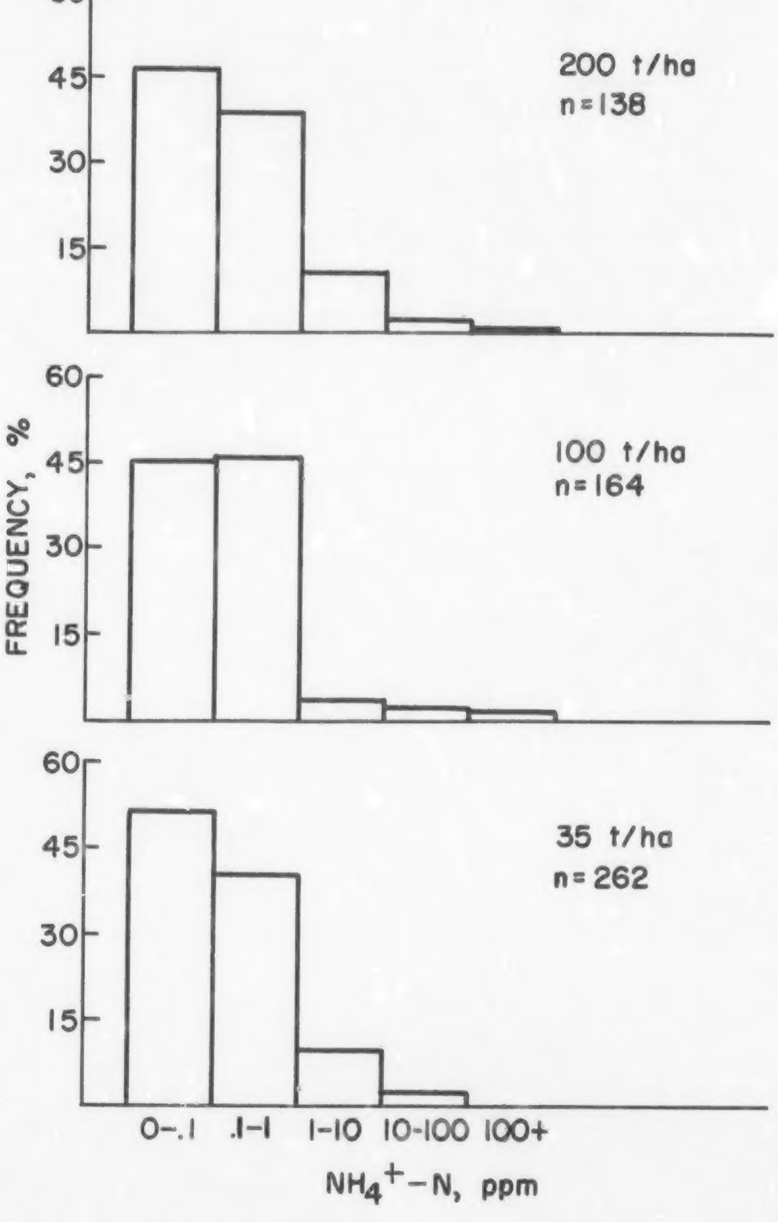

Figure 20. Distribution of ammoniacal nitrogen concentrations in surface runoff with respect to the rate of manure application. 1972, 1973.

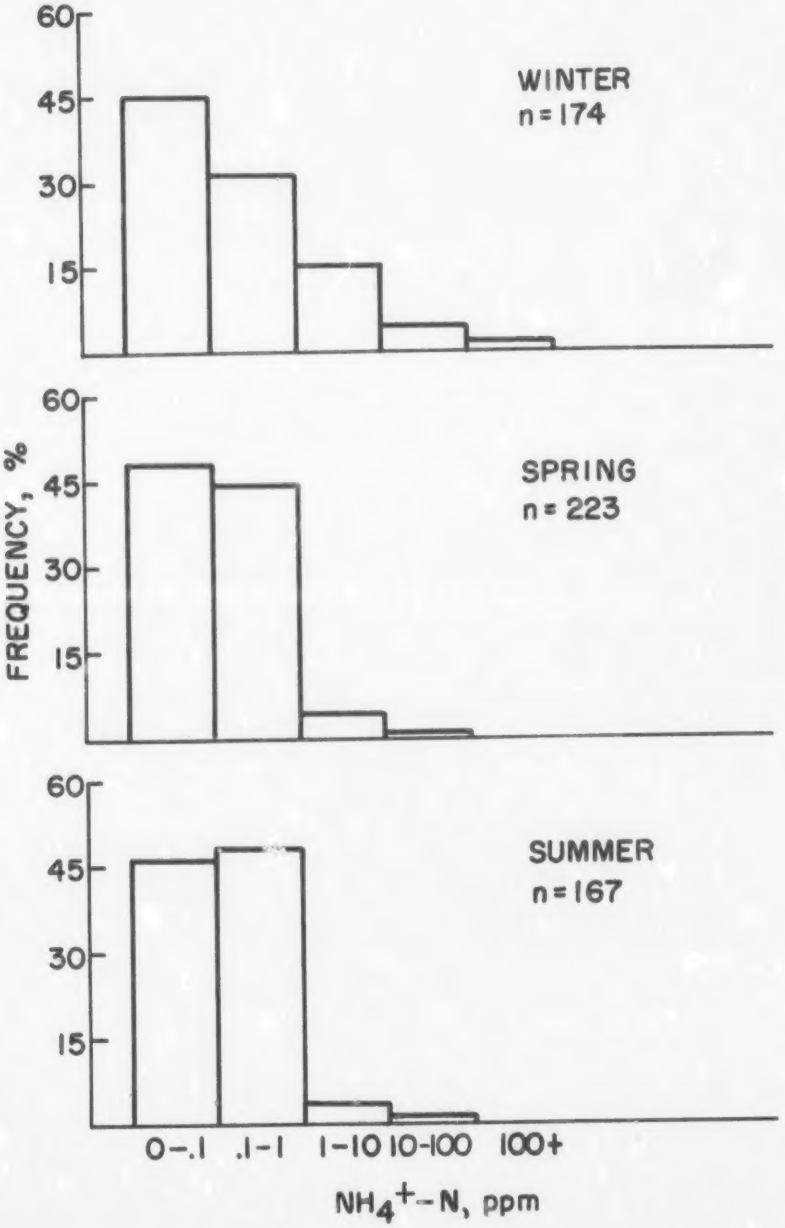

Figure 21. Distribution of ammoniacal nitrogen concentrations in surface runoff with respect to timing of manure application. 1972, 1973.

Table 13. NITRATE NITROGEN CONCENTRATIONS IN SURFACE RUNOFF OVER A TWO YEAR PERIOD. 1972, 1973.

Time of applic	Rate, t/ha	Obs	Mean, ppm	Standard deviation	Coeff of variation, %	Range
Winter	35	91	3.4	5.6	163	.04 - 34.5
	100	36	5.5	9.1	164	.03 - 37.3
	200	47	3.4	6.2	183	.02 - 32.5
Spring	35	104	3.7	7.3	196	.11 - 49.0
	100	68	4.7	6.7	143	.02 - 32.5
	200	50	2.5	2.2	90	.04 - 8.7
Summer	35	67	2.2	2.5	115	.02 - 11.4
	100	60	3.6	4.2	117	.03 - 17.0
	200	40	3.2	5.2	163	.25 - 30.0

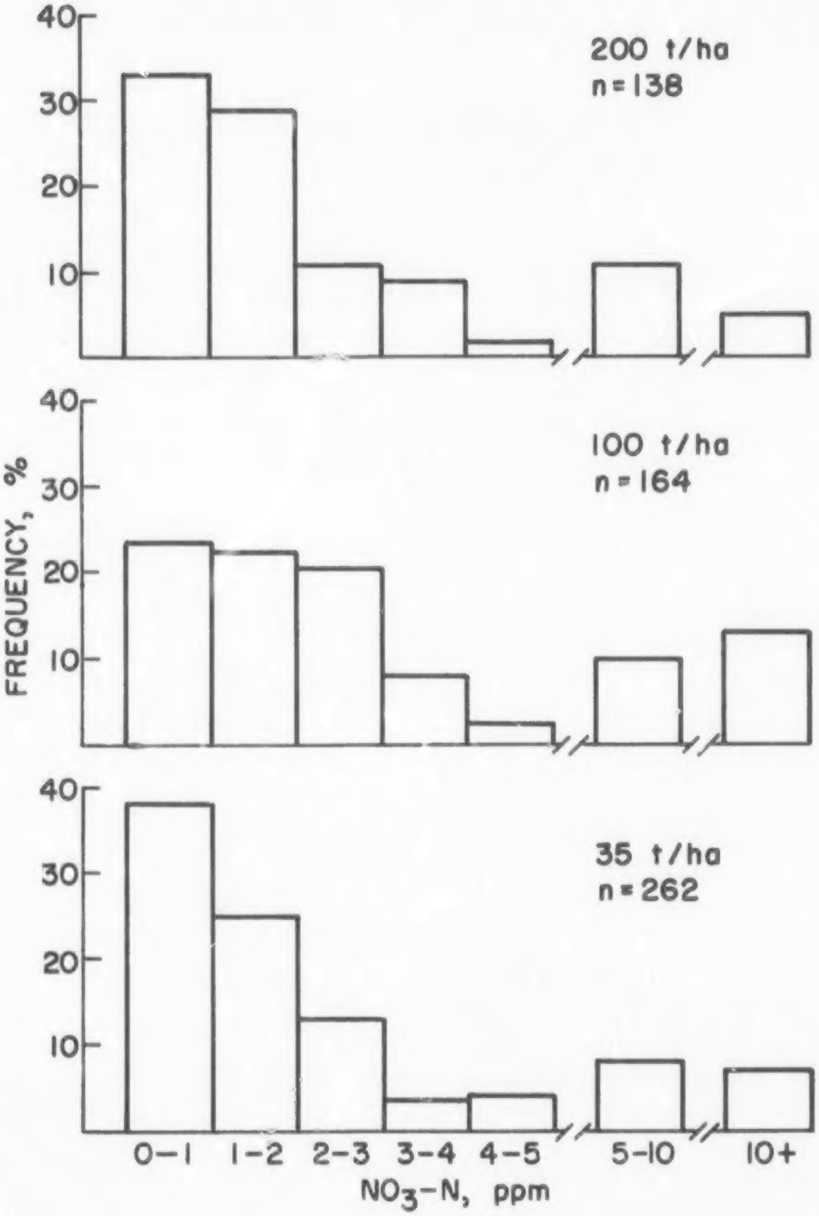

Figure 22. Distribution of nitrate-nitrogen concentrations in surface runoff with respect to the rate of manure application. 1972, 1973.

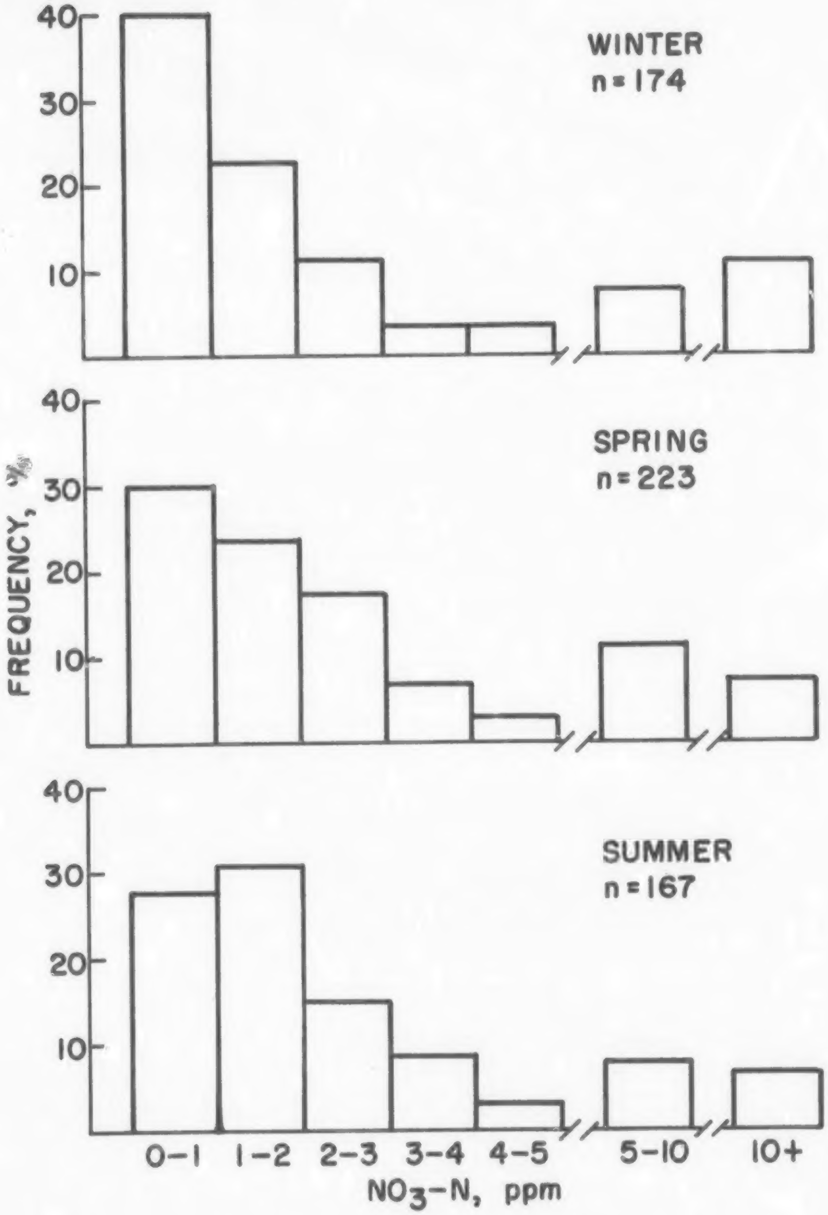

Figure 23. Distribution of nitrate-nitrogen concentrations in surface runoff with respect to timing of manure application. 1972, 1973.

Much like ammoniacal nitrogen, both soluble inorganic and total soluble phosphorus exhibited the greatest mean concentrations for the 100 and 200 t/ha manure application rates for winter disposal (Tables 14 and 15). The concentrations for the 35 t/ha winter disposal treatment were well in line with phosphorus concentrations for the varying disposal rates for the spring and summer applications.

The higher concentrations of phosphorus, as noted in the upper range for the winter application, at the two higher rates of application, were mainly associated with the single snow melt event of February 1972. Phosphorus contained in the manure applied on frozen soil did not have sufficient retention time to interact with the soil, hence mobility of the soluble fraction was retained.

The frequency of these outlying phosphorus concentrations (10+ ppm) was not great (Figures 24 to 27). Over the two year measuring period, approximately 80-90% of the occurrences were less than 1.0 ppm.

Probability - The probability of a nutrient concentration to exceed a given value in surface runoff can be calculated from these frequency distributions. The probability of occurrence can be determined by the "best point estimate" and is defined as:

$$P\,[Z > Y \text{ ppm}] = 1 - F\,[<Y \text{ ppm}]$$

where: P = probability
Z = element in question
Y = stated concentration, ppm
F = frequency

The value of Y, or the determined concentration is arbitrary. Permissible criteria for public water supplies (18) for ammonia and nitrate nitrogen (0.5 and 10 ppm as N, respectively) was selected for convenience. Critical phosphorus concentrations will vary with other water quality characteristics and at this time permissible criteria have not been established. The value of 0.1 ppm for phosphorus was selected arbitrarily.

The best point estimates of the probability of a given manure disposal treatment to exceed a given concentration should be used with a great deal of caution. The study of water transport from a disposal field to a stream or potable water supply is in its infancy. Until transport phenomena are well understood, these data should not be extrapolated.

The best point estimates of the probability that a nutrient concentration will exceed Y for nitrogen and phosphorus is given in Table 16.

Table 14. INORGANIC PHOSPHORUS CONCENTRATIONS IN SURFACE RUNOFF OVER A TWO YEAR PERIOD. 1972, 1973.

Time of applic	Rate, t/ha	Obs	Mean, ppm	Standard deviation	Coeff of variation, %	Range
Winter	35	91	0.69	1.34	193	.01 - 9.7
	100	36	2.27	5.16	227	.04 - 22.3
	200	47	2.74	8.62	313	.01 - 58.0
Spring	35	104	0.13	0.23	180	.01 - 1.8
	100	68	0.22	0.74	333	.003 - 6.0
	200	50	0.96	2.18	227	.01 - 10.9
Summer	35	67	0.25	0.38	151	.02 - 2.6
	100	60	0.23	0.24	104	.01 - 1.3
	200	40	0.43	0.55	129	.003 - 2.3

Table 15. TOTAL SOLUBLE PHOSPHORUS CONCENTRATIONS IN SURFACE RUNOFF OVER A TWO YEAR PERIOD. 1972, 1973

Time of applic	Rate, t/ha	Obs	Mean, ppm	Standard deviation	Coeff of variation, %	Range
Winter	35	91	0.86	1.59	184	.02 - 11.0
	100	36	2.61	5.58	214	.05 - 23.4
	200	47	3.09	8.88	287	.02 - 59.3
Spring	35	104	0.17	0.28	165	.02 - 2.2
	100	68	0.39	1.63	417	.01 - 13.4
	200	50	1.14	2.50	219	.02 - 11.7
Summer	35	67	0.34	0.51	149	.04 - 3.4
	100	60	0.29	0.28	96	.04 - 1.4
	200	40	0.51	0.62	122	.01 - 2.4

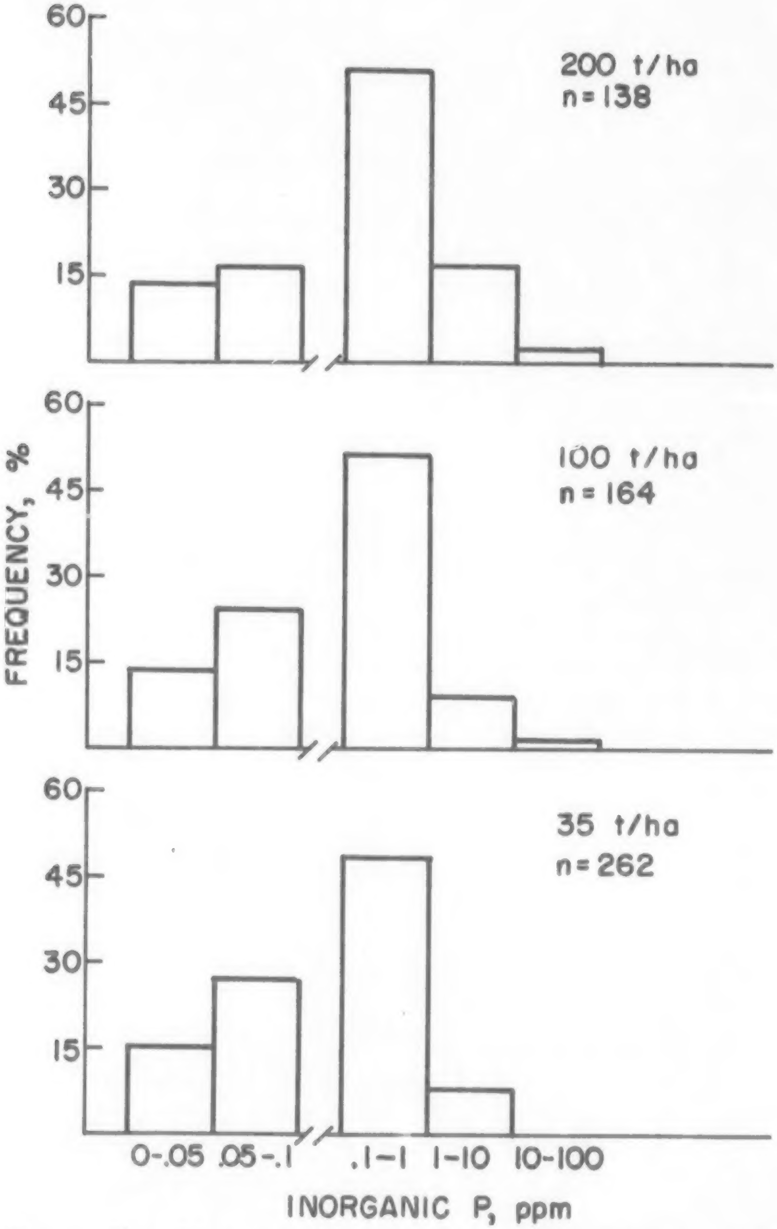

Figure 24. Distribution of inorganic phosphorus concentrations in surface runoff with respect to rate of manure application. 1972, 1973.

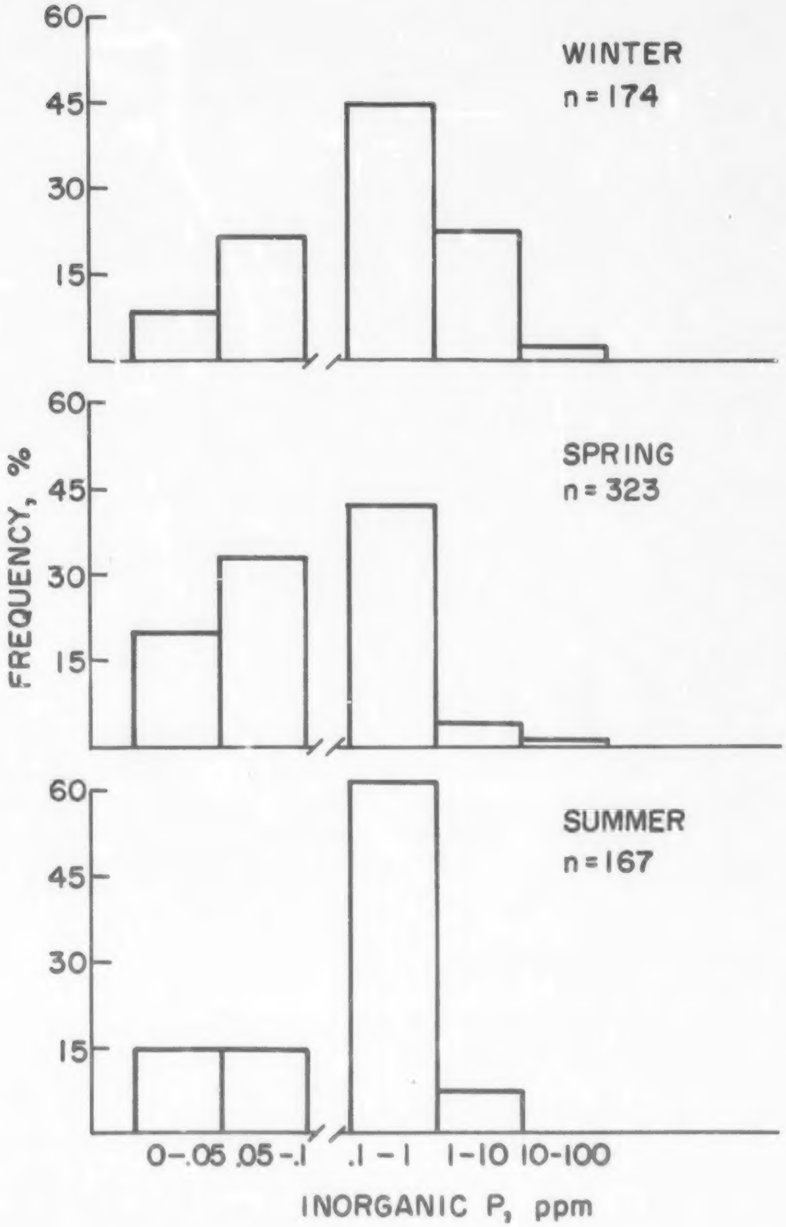

Figure 25. Distribution of inorganic phosphorus concentrations in surface runoff with respect to timing of manure application. 1972, 1973.

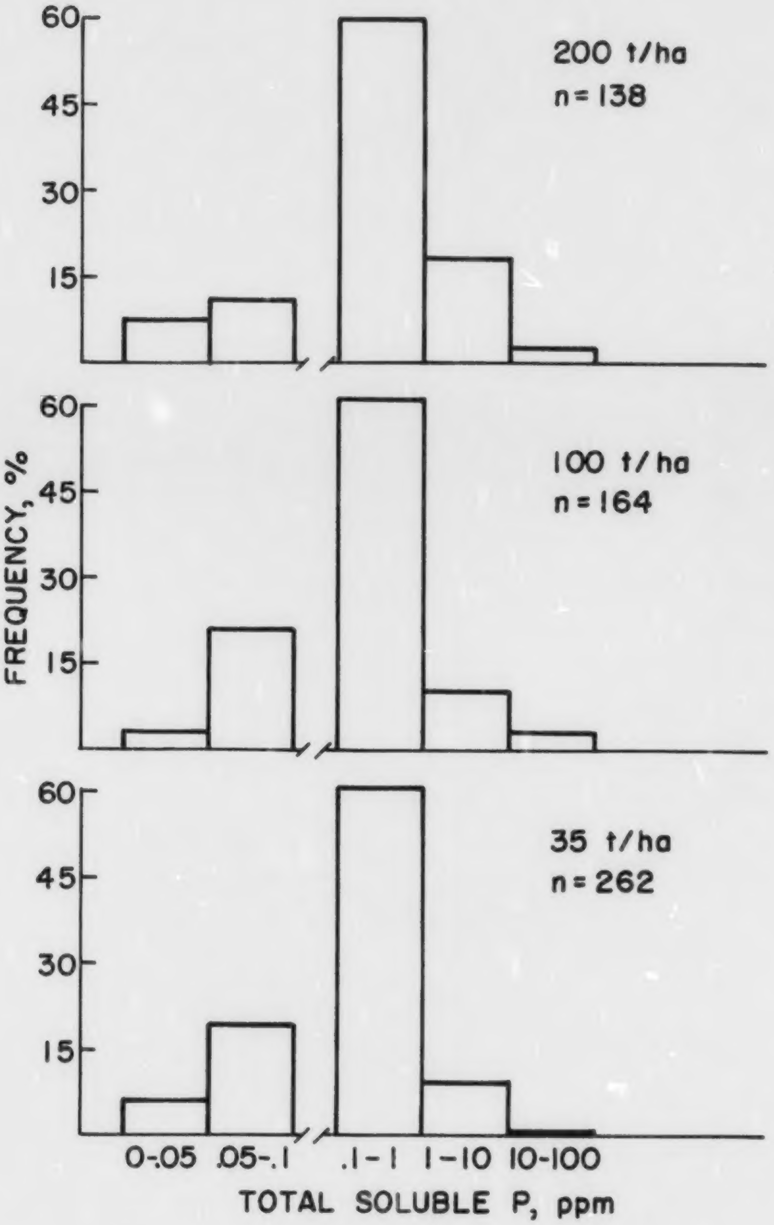

Figure 26. Distribution of total soluble phosphorus concentrations in surface runoff with respect to rate of manure application. 1972, 1973.

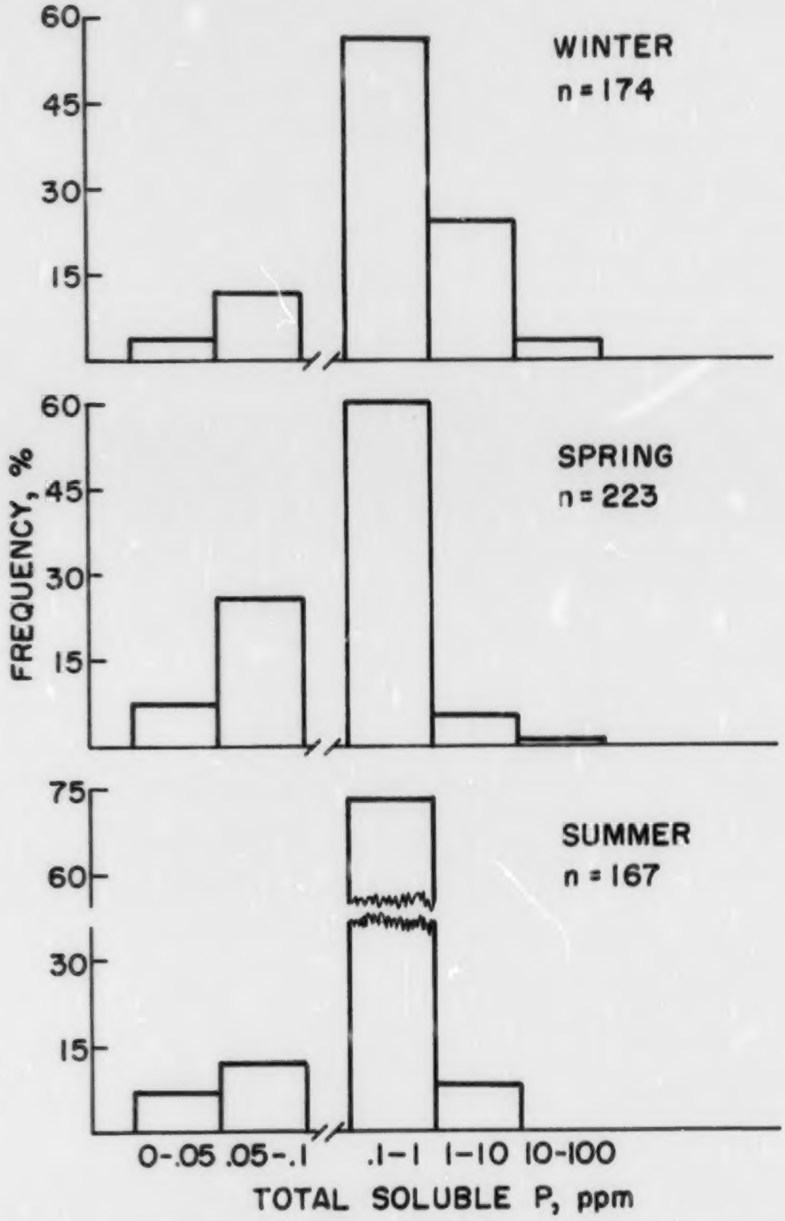

Figure 27. Distribution of total soluble phosphorus concentrations in surface runoff with respect to timing of manure application. 1972, 1973.

Table 16. BEST POINT ESTIMATE OF THE PROBABILITY THAT A CONCENTRATION OF NITROGEN OR PHOSPHORUS (Z) IN SURFACE RUNOFF WILL EXCEED Y.

Element Y, ppm		NH_4-N 0.5	NO_3-N 10.0	Inorganic-P 0.1	Total-solu-P 0.1
Time of application	Rate of applic, t/ha	P[Z>Y], %			
Winter	35	24	2	64	79
	100	33	14	81	86
	200	28	9	72	92
Spring	35	9	7	37	62
	100	9	13	46	63
	200	20	<1	70	78
Summer	35	24	3	78	88
	100	15	12	67	83
	200	8	5	68	70

The winter application proved to have the higher incidence of surface runoff exceeding 0.5 ppm of NH_4-N. The spring application at the two lower rates as well as the summer application at the maximum rate yielded the lowest probabilities of exceeding 0.5 ppm NH_4-N. Plowing down manure, as in the case of the spring application, would reduce surface exposure of manure and lessen the probability of NH_4-N transport, especially at the lower rates of application.

There is a consistent trend for the 100 t/ha rate of application, regardless of the time of disposal, to exhibit a higher incidence of surface runoff exceeding 10 ppm of NO_3-N. It has been pointed out in previous discussions that none of the plots receiving 100 t/ha are tile drained. The lack of artificial internal drainage on these imperfectly drained soils would inhibit the downward movement of NO_3-N. Accumulations of NO_3-N at, or near, the soil surface could result.

The spring plowdown of 35 and 100 t/ha, especially for inorganic-P, displayed a marked reduction with respect to the frequency at which runoff concentrations exceed 0.1 ppm. Similar to NH_4-N, plowing reduces surface exposure of manure and enhances soil fixation. All other treatments showed general uniformity.

Tile effluent - Analytical determinations were made for ammoniacal and nitrate nitrogen, soluble inorganic and total soluble phosphorus in tile effluent. The actual nutrient concentration found in tile effluent, as noted in the section dealing with annual nutrient discharges in tile effluent, is not necessarily an ideal criteria for determining the pollution potential of groundwater. The total amount of nutrients delivered to a stream or lake may be more meaningful in determining the ultimate impact of the nutrients on water quality. The tile sampling scheme has been described previously in the section dealing with methods and materials. Samples were taken weekly and represent a composite of flow during that period, rather than being specific for a precipitation event.

Ammoniacal nitrogen - Concentration of ammoniacal nitrogen in weekly tile effluent sample showed a greater degree of variation (Table 17) than in surface water samples (Table 12). Mean concentrations, however, were an order of magnitude lower in the tile effluent. Soil immobilization, nitrification and ammonia volatilization from surface applied manure may account for this reduction.

The maximum concentrations, noted in the range, occurred very infrequently (3% of the time). There was general uniformity in the frequency of NH_4-N concentrations over both rates of application and over the three times of application (Figures 28 and 29). This

Table 17. AMMONIUM NITROGEN CONCENTRATIONS IN WEEKLY TILE EFFLUENT SAMPLES. 1972, 1973.

Time of applic	Rate, t/ha	Obs	Mean, ppm	Standard deviation	Coeff of variation, %	Range
Winter	35	96	0.059	0.266	450	.001 - 2.55
	200	122	0.249	0.871	349	.001 - 6.25
Spring	35	161	0.058	0.172	294	.001 - 1.40
	200	117	0.195	0.881	452	.001 - 7.50
Summer	35	83	0.178	0.695	392	.001 - 4.00
	200	125	0.104	0.561	539	.001 - 5.75

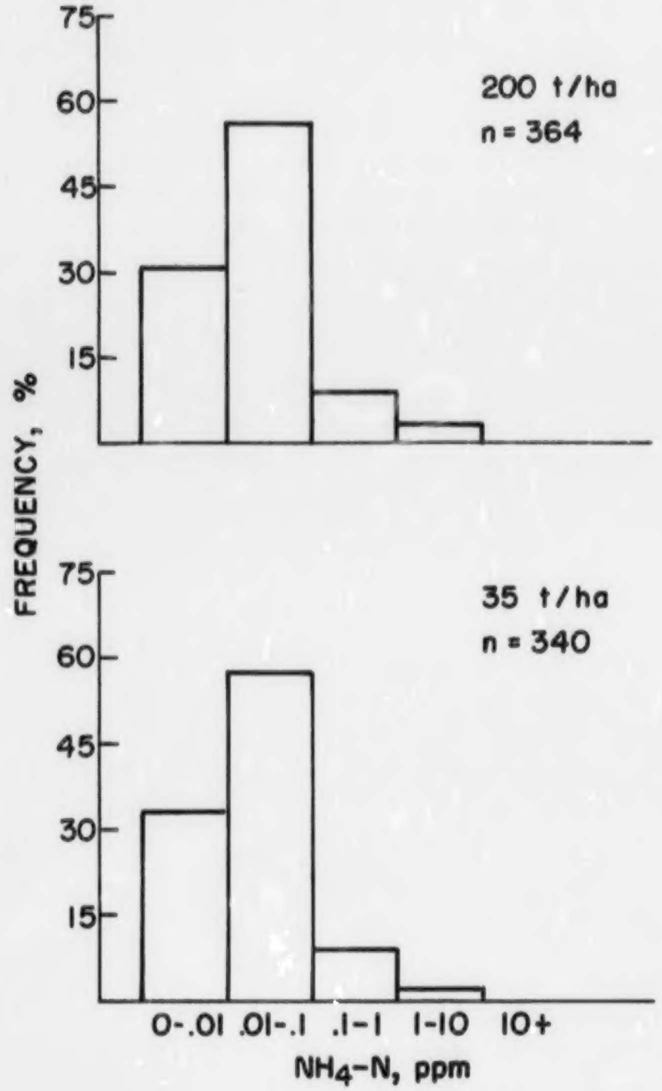

Figure 28. Distribution of ammoniacal nitrogen concentrations in tile effluent with respect to the rate of manure application. 1972, 1973.

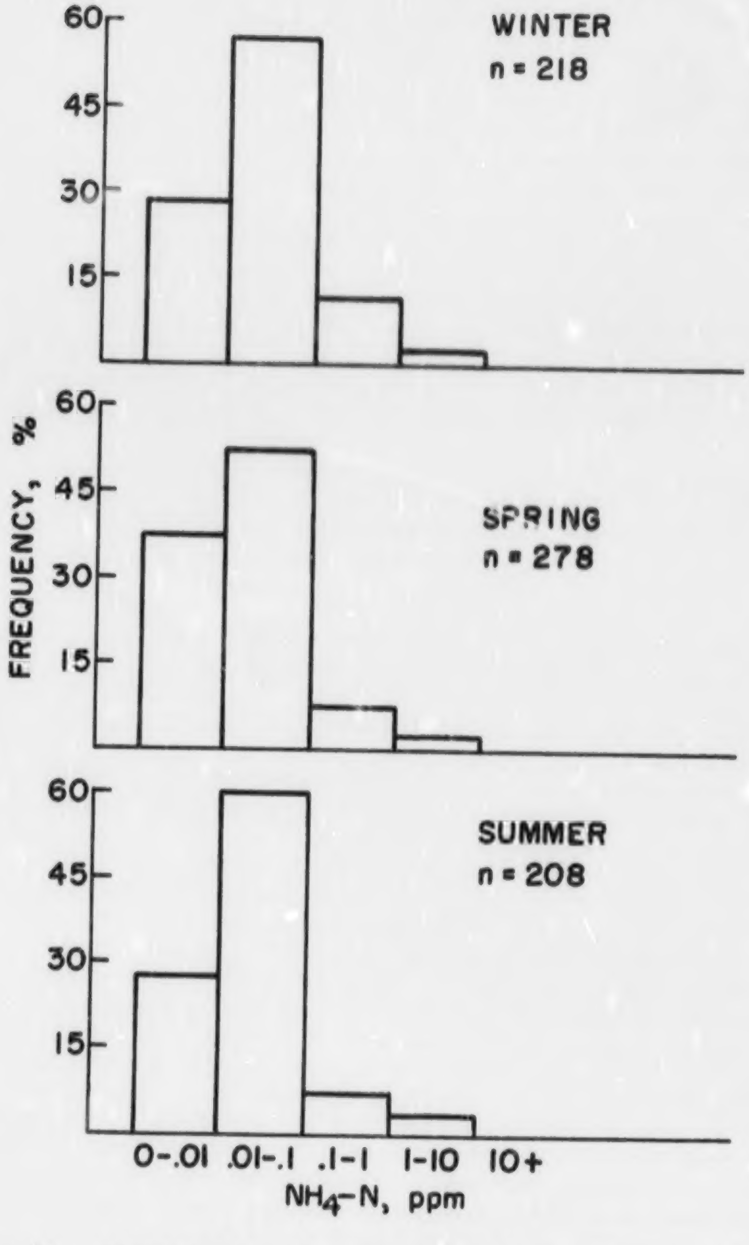

Figure 29. Distribution of ammoniacal nitrogen concentrations in tile effluent with respect to timing of manure application. 1972, 1973.

general uniformity strongly indicates that rate and timing of manure disposal per se is not influential. Soil fixation and probably nitrification and/or ammonia volatilization may be adequately controlling NH_4-N concentrations in the tile effluent in all treatments.

Nitrate nitrogen - Nitrate is highly mobile and moves readily with water as it leaches through the soil. The lowest mean concentration was associated with the plowing down of 35 t/ha in the spring (Table 18). The extreme concentrations shown in the upper limit of the range were not all a consequence of manure additions. Manure additions began in February 1972. The starting point, as a matter of convenience, was January 1, 1972 to enhance calendar year accounting. The high concentrations of 62.3, 106.5 and 126.5 in the upper range (Table 18) occurred about 2 weeks prior to the winter application. The remaining maximum concentrations occurred from 2 to 12 months after application. The availability of NO_3-N with time is largely a function of the rate of nitrification.

The frequency of NO_3-N concentrations exceeding 10 ppm ranged from 45 to 70% of the time (Figures 30 and 31). The 200 t/ha rate and the winter and summer disposal periods approached the 70% frequency level while the 35 t/ha rate and the spring disposal period accounted for the 45% frequency level.

Phosphorus - Tables 19 and 20 present statistical data for soluble inorganic and total soluble phosphorus concentrations. The mean concentrations for the winter and spring 35 t/ha rates are much lower than the 200 t/ha rates. Even though the soil does have a large capacity to hold phosphorus, the higher concentrations from the 200 t/ha rates above the 35 t/ha rates might be expected, especially when the amounts of phosphorus applied in the manure are considered. The 35 t/ha treatments received on the average nearly 40 kg of phosphorus as soluble inorganic phosphorus in 1972 and 50 kg in 1973, whereas the 200 t/ha rates received nearly 190 kg in 1972 and 260 kg in 1973. Although phosphorus is quite effectively adsorbed and immobilized in the soil, some phosphorus continues to move downward with soil water. A more complete explanation of phosphorus chemistry in the soil and how phosphorus additions in manure affect soil solution phosphorus levels will be discussed later in this section. Standard deviations and coefficients of variation are high and at first glance may be distressing. This variability simply reflects the kind of variation one encounters under normal field and weather conditions, because of the inherent diversity of natural systems. A look at the ranges of the values also confirms this and helps point out why the variability was large.

Table 18. NITRATE NITROGEN CONCENTRATIONS IN WEEKLY TILE EFFLUENT SAMPLES. 1972, 1973

Time of applic	Rate, t/ha	Obs.	Mean, ppm	Standard deviation	Coeff of variation, %	Range
Winter	35	96	16.66	13.27	450	0.05 - 62.30
	200	122	18.30	18.32	101	0.06 -147.25
Spring	35	161	7.07	5.62	79	0.09 - 57.25
	200	117	22.45	23.94	107	0.20 -126.50
Summer	35	83	15.85	15.34	97	0.06 -106.50
	200	125	17.48	16.14	92	0.18 - 80.50

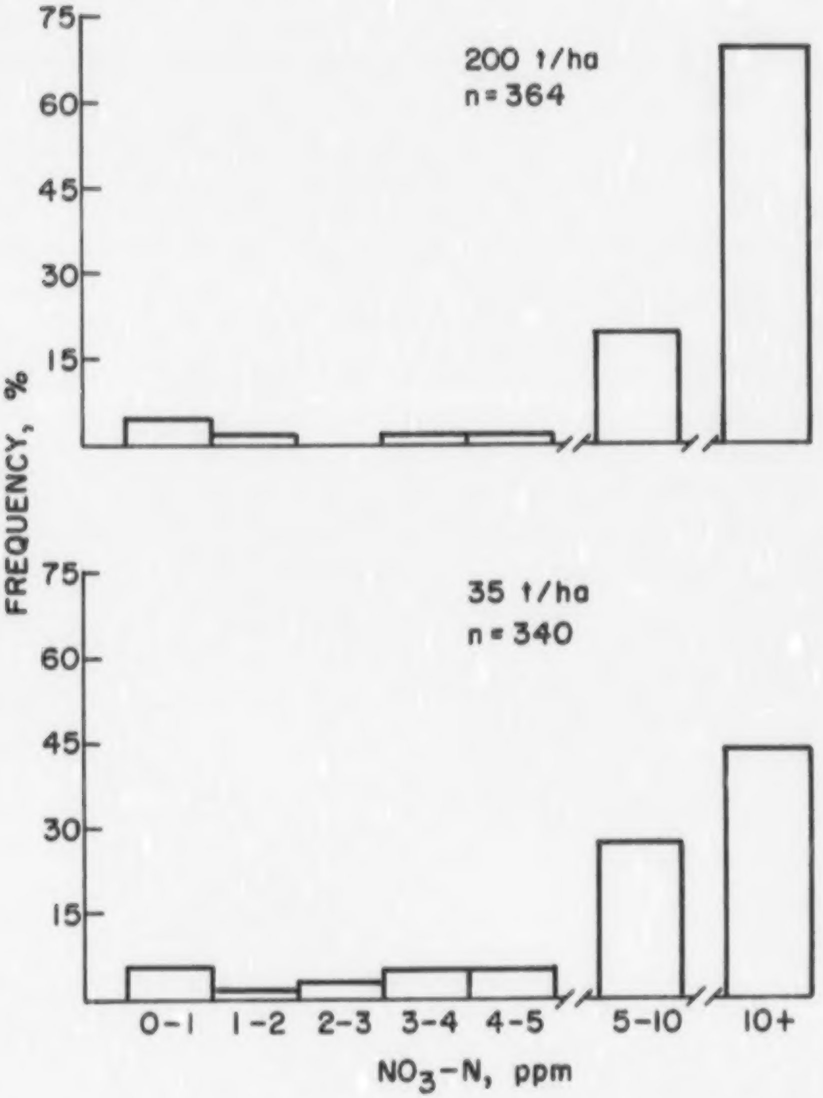

Figure 30. Distribution of nitrate-nitrogen concentrations in tile effluent with respect to the rate of manure application. 1972, 1973.

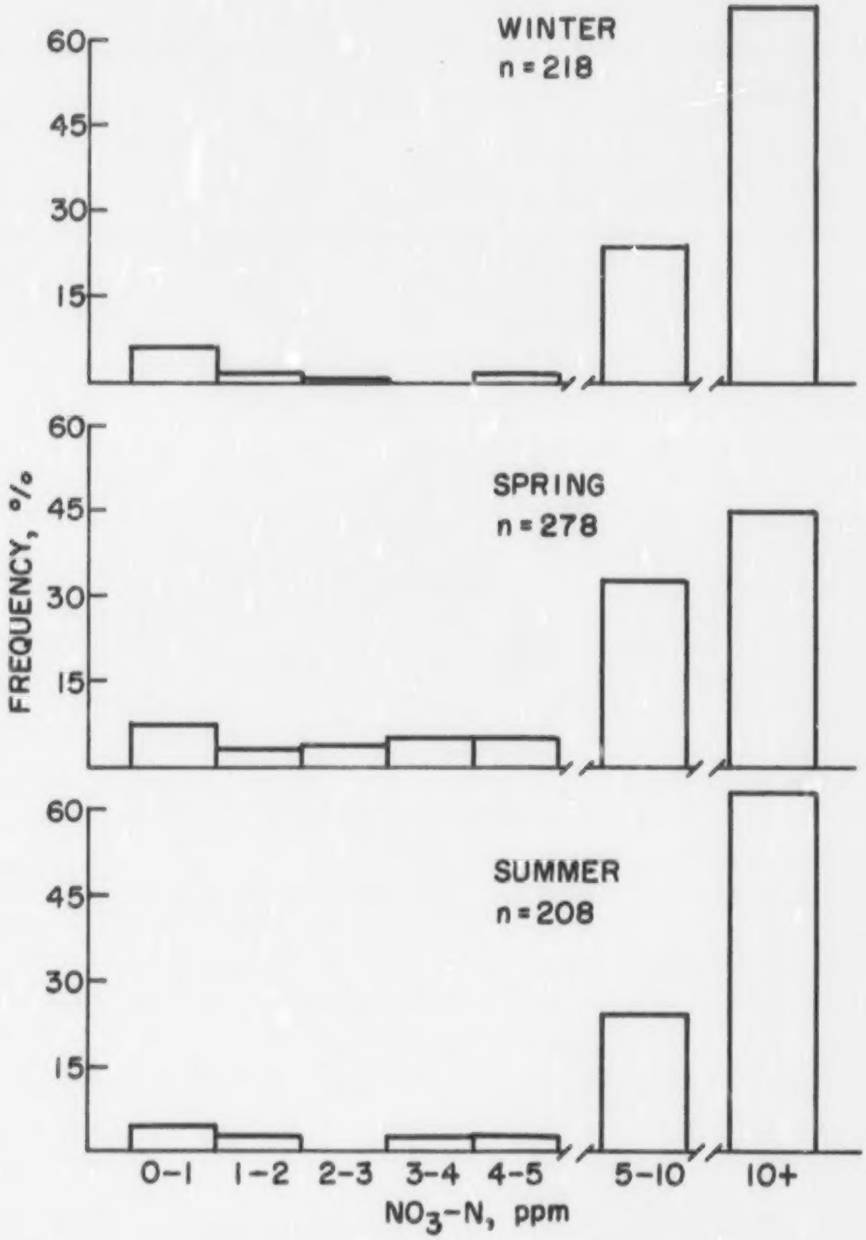

Figure 31. Distribution of nitrate-nitrogen concentrations in tile effluent with respect to the timing of manure application. 1972, 1973.

Table 19. INORGANIC PHOSPHORUS CONCENTRATIONS IN WEEKLY TILE EFFLUENT SAMPLES. 1972, 1973.

Time of applic	Rate, t/ha	Obs	Mean, ppm	Standard deviation	Coeff of variation, %	Range
Winter	35	96	0.009	0.016	183	.001 - 0.049
	200	122	0.188	0.639	340	.001 - 5.220
Spring	35	161	0.009	0.019	204	.001 - 0.137
	200	117	0.115	0.388	337	.001 - 3.700
Summer	35	83	0.043	0.095	222	.001 - 0.590
	200	125	0.046	0.096	210	.001 - 0.640

Table 20. TOTAL SOLUBLE PHOSPHORUS CONCENTRATIONS IN WEEKLY TILE EFFLUENT SAMPLES. 1972, 1973.

Time of applic	Rate, t/ha	Obs	Mean, ppm	Standard deviation	Coeff of variation, %	Range
Winter	35	96	0.020	0.026	127	.001 - 0.110
	200	122	0.255	0.835	327	.001 - 6.800
Spring	35	161	0.018	0.027	154	.001 - 0.202
	200	117	0.149	0.445	299	.001 - 4.100
Summer	35	83	0.058	0.106	183	.003 - 0.606
	200	125	0.065	0.141	216	.001 - 1.086

Figures 32 and 33 illustrate the frequency distributions of soluble inorganic phosphorus and total soluble phosphorus concentrations, respectively, for the two rates of manure application. These figures give a clearer picture of where most of the concentrations fall. There is little difference between the soluble inorganic phosphorus and total soluble phosphorus concentration distributions within one rate, as soluble inorganic phosphorus usually accounts for >85% of the total soluble phosphorus. A marked effect of treatment on concentration distributions can be seen when the 35 and 200 t/ha rates are compared (Figure 32 and 33). The higher rate of manure shifts the frequency of concentrations to higher levels.

Returning to Tables 19 and 20, it will be noted that soluble inorganic phosphorus and total soluble phosphorus mean concentration values for the 200 t/ha summer application were much lower than for the 200 t/ha winter and spring applications. Little difference is apparent, however, between the effect of application time on the distribution of tile effluent soluble inorganic phosphorus concentrations when averaged over both rates of application (Figure 34). The pattern of concentration distributions between 0 and 0.1 ppm is very similar for all application times. The lower mean for the summer application of 200 t/ha can be explained by the fact that there was a smaller percentage of samples in the greater than 0.1 ppm categories for the summer than for the spring or winter applications. A few samples in the higher ranges can shift the mean considerably higher while showing little effect on the frequency distribution. This same pattern is also apparent for the total soluble phosphorus (Table 20 and Figure 35).

There has been a standard belief that phosphorus is fixed within the soil. Although true, this leads one to believe that none or only very minute amounts of phosphorus would be expected in soil leachates. Confusion about phosphorus availability is evident, and a brief explanation dealing with phosphorus reactions in soil may help clarify the problem. When phosphorus is applied to the soil in a very soluble form such as soluble phosphorus in manure, it immediately begins to react with the soil. Phosphorus compounds found in soil are very insoluble and the chemistry of phosphorus is such that it does not remain in solution at high concentrations for very long. The chemistry of the inorganic phosphate ion, $H_2PO_4^-$ or $HPO_4^=$ is completely different than that of a soluble ion such as nitrate (NO_3^-). Phosphate can truly be considered a very slightly soluble ion in a soil system. In the absence of plants, phosphorus concentrations in soil solution may be reduced by two processes. The first is adsorption of the phosphate by minerals or clays in the soil. The second is by precipitation of very

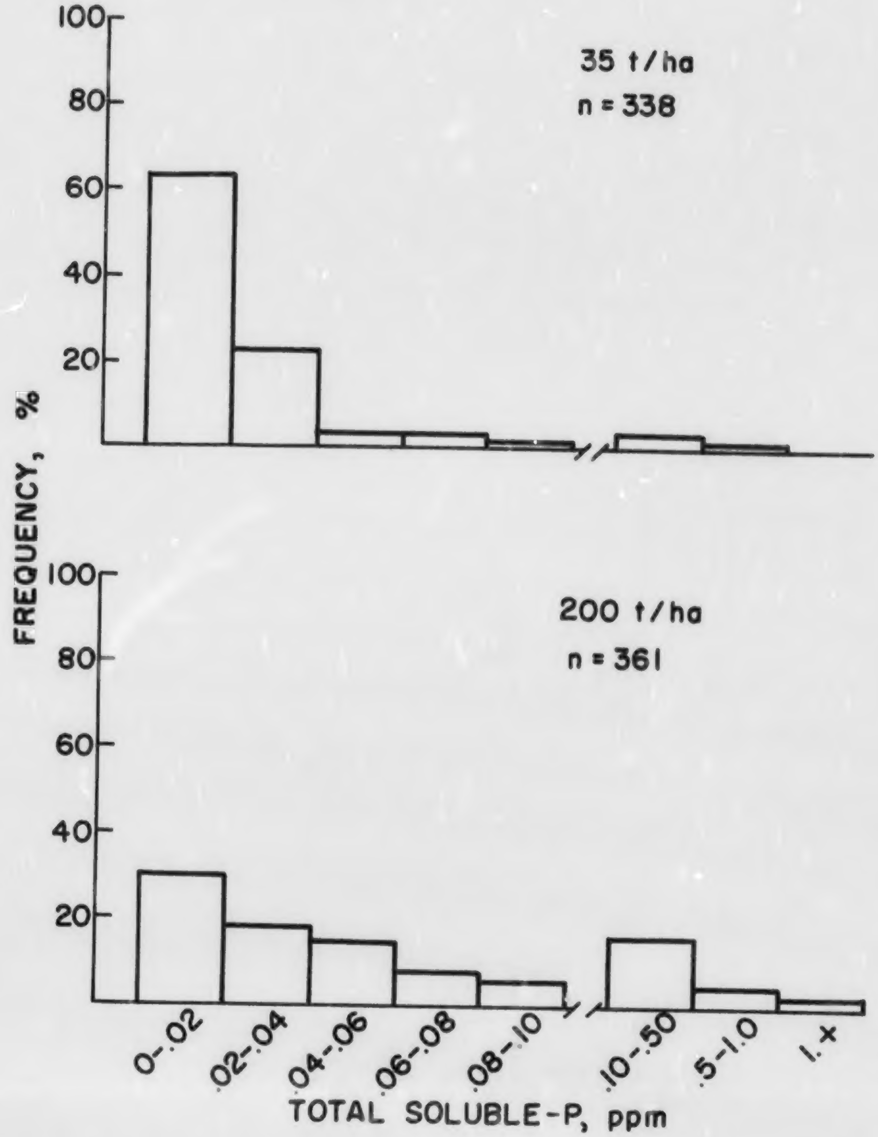

Figure 33. Distribution of total soluble phosphorus concentrations in tile effluent with respect to the rate of manure application. 1972, 1973.

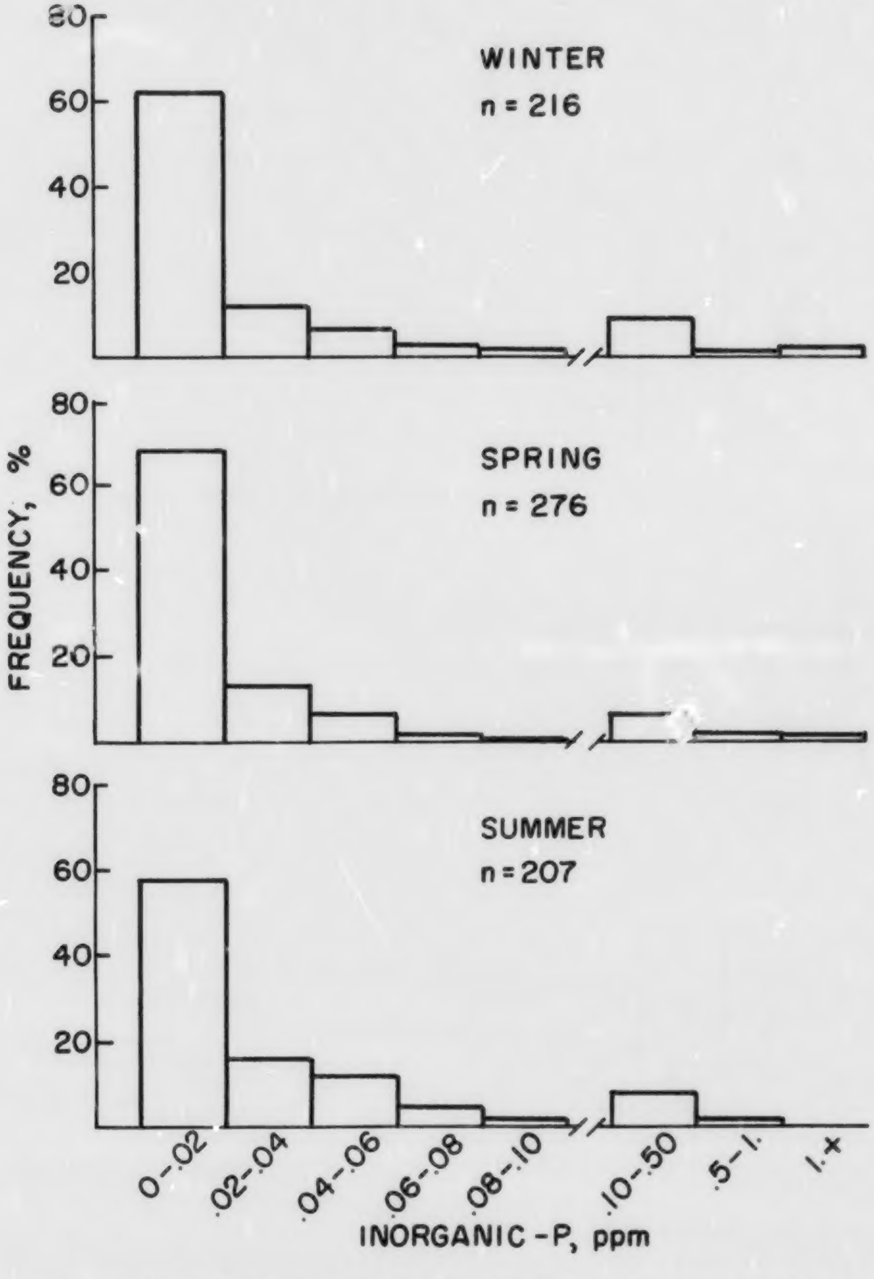

Figure 34. Distribution of inorganic phosphorus concentrations in tile effluent with respect to timing of manure application. 1972, 1973.

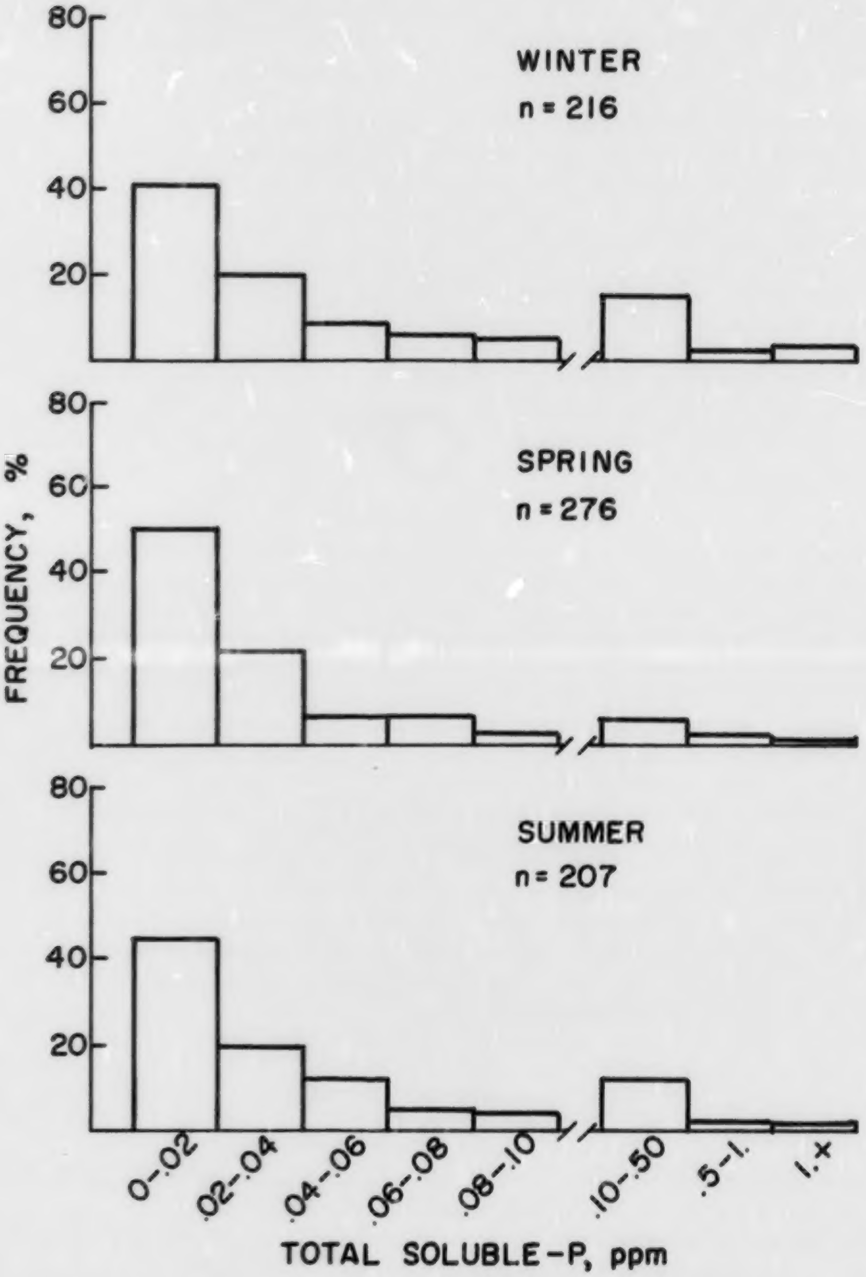

Figure 35. Distribution of total soluble phosphorus concentrations in tile effluent with respect to the timing of manure application. 1972, 1973.

insoluble phosphorus compounds. In the case of the high lime soil in this experiment, phosphorus is precipitated as calcium phosphate. The sorption reaction is quite rapid, occurring within minutes and continuing for several days. The precipitation reaction is much slower, occurring within hours, and proceeding for years.

Possible reactions of soil solution phosphorus are shown in Figure 36. Phosphorus in soil solution may be present in either inorganic or soluble organic compounds. The organic phase can be mineralized to inorganic phosphorus by soil microbial activity or some inorganic phosphorus may be utilized by microbes for growth and incorporated into organic phosphorus Adsorbed phosphorus may slowly be changed to slightly soluble phosphorus compounds but the exact mechanisms of this change are not well understood.

One of the characteristics of a soil is its phosphorus sorption capacity which can be determined in the laboratory. The value gives some idea of how much phosphorus a soil can adsorb. Some representative values for the soil of this experiment are in the range of 300 to 350 mg P adsorbed for each kg of soil.

A hectare of land to a depth of 30 cm could adsorb between 1200-1400 kg phosphorus. In light of the amounts of phosphorus applied in manure (see Tables A9, A10 Appendix) after two years, the soil is still well below its phosphorus sorption capacity, but still there had been an increase in the tile effluent phosphorus concentrations. Soil solution levels of phosphorus can change even though enough phosphorus has not been added to satisfy the sorption capacity of the soil. In a previously unfertilized soil, phosphorus concentrations in soil solution may be in the range of 0.005 to 0.010 ppm as soluble inorganic phosphorus. The concentration found in soil solution is often referred to as the Intensity Factor for soil solution phosphorus. If soil solution concentrations of phosphorus fall due to plant uptake, phosphorus will be released from the adsorbed phase and possibly some from the slowly soluble phosphorus compounds to maintain the phosphorus concentration. This aspect of replenishment is referred to as the Capacity Factor. When phosphorus is added to soil from manure, soil solution levels of phosphorus increase rapidly but then soon begin to decrease due to adsorption and precipitation reactions. Intensity (soil solution phosphorus concentration) increases then decreases; capacity slowly increases with additions of phosphorus to the soil.

The new phosphorus concentration levels in soil solution after a manure addition will be higher than previous levels. If this new higher level of phosphorus is depleted by plant growth, the capacity factor will replenish soil solution phosphorus levels to its previous level.

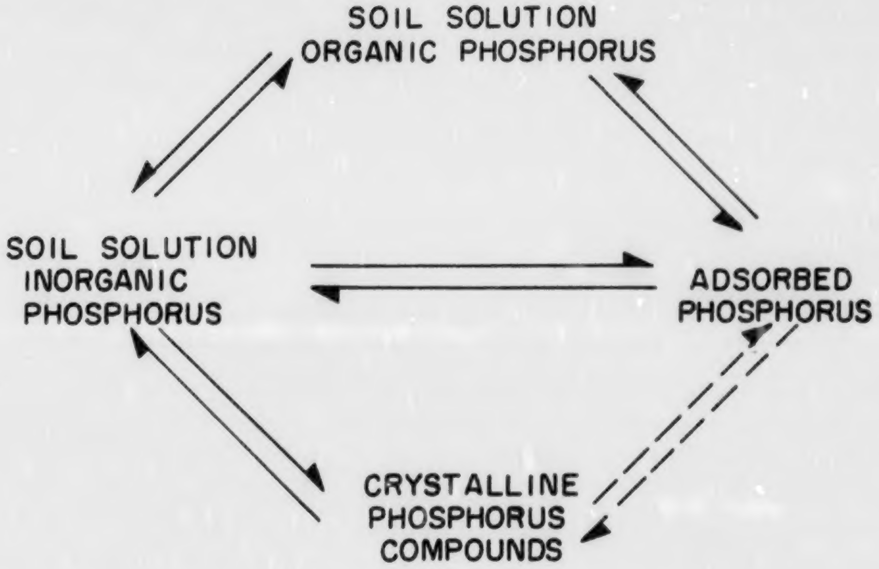
SOIL SOLUTION
ORGANIC PHOSPHORUS
SOIL SOLUTION
INORGANIC
PHOSPHORUS
ADSORBED
PHOSPHORUS
CRYSTALLINE
PHOSPHORUS
COMPOUNDS

Figure 36. Phosphorus reactions in soil solution.

Phosphorus in solution can move downward through the soil and, in the case of tile drained soils, eventually reach the tile. The subsoil also has a high phosphorus sorption capacity but usually has a very low phosphorus capacity factor. This means that high phosphorus concentrations in soil solution moving down from the plow layer will be "scrubbed" of phosphorus by the adsorption processes in the subsoil.

After manure application, tile flow from a manured field may show little or no increase in soluble phosphorus concentration. As more and more phosphorus moves into the subsoil, the intensity and capacity of the subsoil are also increased. After this time, an increase in tile effluent phosphorus concentrations may be noted. Soil water which was not intercepted by the tile and continued to move deeper into the soil would lose phosphorus by soil sorption or precipitation, so water reaching lower levels would have lower phosphorus concentrations. From this discussion, it can be seen why adding large amounts of phosphorus in manure eventually has an effect on tile effluent phosphorus concentrations. It should also point out why concentrations found in tile effluent are probably not representative of phosphorus concentrations found in ground water.

Probability - The probability of a nutrient concentration in tile effluent exceeding a given value can be calculated from the frequency distribution. The probability of occurrence can be determined by the "best point estimate." The procedure has been discussed in this section dealing with surface runoff nutrient concentrations.

The best point estimate of the probability of nitrogen and phosphorus exceeding a given concentration in the tile effluent is presented in Table 21. In general, there is a relatively low probability of tile effluent exceeding 0.5 ppm NH_4-N, but a very high probability of exceeding 10 ppm of NO_3-N. The major difference being a greater mobility of nitrate in comparison to ammonium and the shift of nitrogen to the oxidized form in an aerobic system.

The probability of phosphorus concentrations exceeding 0.1 ppm is very minute for the lower rate of application during the winter and spring dispoasl periods. Differences in probability estimates based on rate for the summer disposal period are essentially nonexistent.

Reference to Table 16 clearly demonstrates that surface waters have a greater tendency to yield higher concentrations of NH_4-N and lower concentrations of NO_3-N than does tile effluent. The probability of phosphorus concentrations exceeding 0.1 ppm are far greater in surface runoff in contrast to tile effluent.

Table 21. BEST POINT ESTIMATE OF THE PROBABILITY THAT A CONCENTRATION OF NITROGEN OR PHOSPHORUS (Z) IN TILE EFFLUENT WILL EXCEED Y.

Element Y, ppm		NH_4-N 0.5	NO_3-N 10	Inorganic-P 0.1	Total solu-P 0.1
Time of application	Rate of applic, t/ha	P [Z>Y], %			
Winter	35	1	64	<1	2
	200	8	69	22	32
Spring	35	3	18	1	1
	200	4	82	18	21
Summer	35	5	69	12	13
	200	3	63	9	14

Rainfall Simulation -

An irrigation experiment was initiated to study the movement of soluble nitrogen and phosphorus with time during a runoff event. With this situation, a calculation of discharge rates of nitrogen and phosphorus with time could be determined. In addition to loading rate calculations, it was of interest to record the concentration of nitrogen and phosphorus in surface runoff and tile effluent with time during a single drainage event.

An estimate of the maximum amount of nutrient loss that can be expected after manure remained on the soil surface for a period of time was desired. A demonstration plot which received 200 metric tons/ha of manure on June 12 was selected. The irrigation experiment started on October 29, 1973. During the intermediate months, 20 cm of rainfall occurred (9.3 cm below average) and less than 0.02 cm of runoff was produced from this plot. Water was applied to the 0.32 ha plot by sprinkler irrigation at the rate ranging from 6 to 11 cm/hr during a two day period to bring the soil to saturation. The following morning, irrigation water was applied at a constant rate of 6 cm/hr for an additional 4.5 hours to produce runoff and tile discharge.

Water samples were collected to correspond to various segments on the hydrograph for both surface runoff and tile discharge. Surface runoff continued for 26 hours and tile flow continued over the next several weeks, compounded by additional rainfall at later dates. Water samples were analyzed for nitrogen and phosphorus as described in the section on Methods and Materials.

A total of 16.4 cm (530 m^3) had been applied over the three day period. Surface runoff and tile discharge occurred after 13.5 cm (436 m^3) and 10 cm (321 m^3) of water were applied respectively.

Surface runoff - The volume of runoff in addition to the concentration of nitrogen and phosphorus is presented in Figure 37. It is evident that the nutrient concentrations did not vary greatly with the volume of discharge water and a nearly constant concentration was maintained. Nutrient concentration began to drop markedly only as the cessation of flow was approached. By 1000 hours on the second day of runoff, there was no longer any water moving across the surface of the soil. The last 4 hours of flow was "tail flow" in which laterally moving subsurface water, at a shallow depth, was being intercepted by the drainage ditch and diverted to the recording flume. Concentrations of nitrogen and phosphorus in this subsurface water were somewhat lower than in the water moving across the surface.

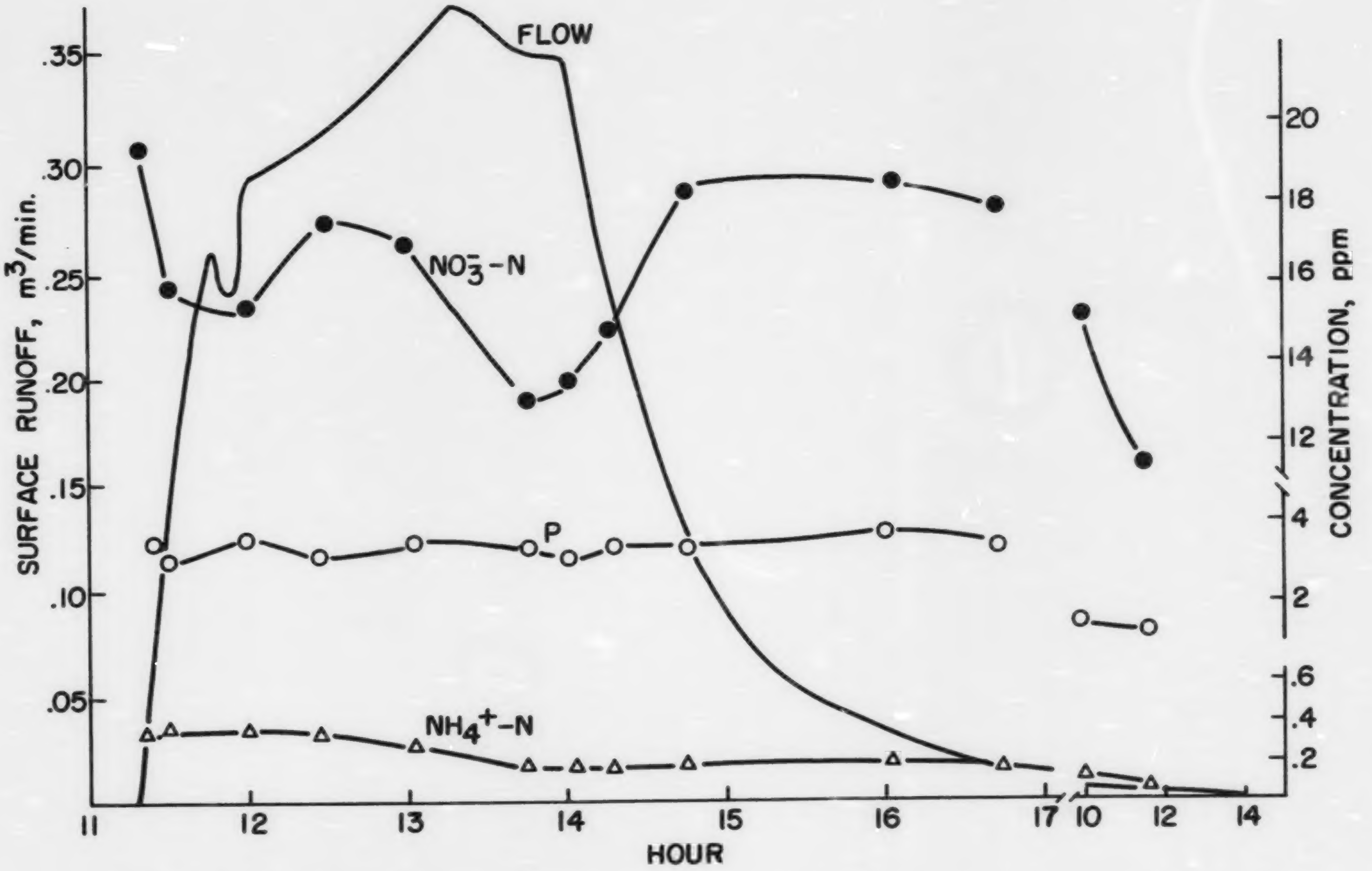

Figure 37. Concentration of nitrogen and total soluble phosphorus during a surface runoff event.

The concentration of NO_3-N ranged from 11-19 ppm throughout the runoff event with a mean value of 16 ppm for the event. Using less than 10 ppm as a guide for acceptable water quality for potable water (18), nitrogen concentration being discharged during this runoff event were above acceptable limits. Total soluble phosphorus concentrations ranged between 1-4 ppm with a mean value of 3.1 ppm. To date, a maximum phosphorus concentration for potable water has not been established.

Extreme care should be used when interpreting these concentrations in runoff water for several reasons. First, these nutrient losses are considered to be an overestimate of what actually occurs in a watershed. Manure was spread from adjacent to to a maximum of 60 meters from the interceptor ditch which diverts water to the sampling device. In actual practice, this would be analagous with spreading manure adjacent to a stream bank. Secondly, the behavior of nitrogen and phosphorus in transport from a disposal field to a well defined watercourse is not well understood. Nutrient loading to a watercourse would depend on length of travel, additional diluting water, topography, soils, vegetation, etc. Thirdly, loading rates approaching 200 metric tons/ha over extensive areas is not a common occurrance. The data presented, however, become extremely important when studying the behavior of nitrogen and phosphorus losses from a well defined disposal field. Extrapolation of nutrient loadings from a segment of a watershed to a stream or lake should be done with caution.

The discharge rates of inorganic nitrogen (NO_3^--N + NH_4^+-N) and total soluble phosphorus for this runoff event are illustrated in Figure 38. Since the quantity of discharge is directly proportional to the flow and the concentration of nitrogen and phosphorus are relatively constant, a linear response is achieved. Correlation coefficients for flow vs nutrient discharge for nitrogen and phosphorus were 0.99 and 0.98 respectively.

The loss of inorganic nitrogen in surface water for the entire runoff event was 3.9 kg/ha. Approximately 1.0% of the inorganic nitrogen was as ammonium nitrogen, the remaining as nitrate nitrogen. The total soluble phosphorus loss during the same event was 0.8 kg/ha with 90% being soluble inorganic and the remainder as soluble organic phosphorus.

Tile drainage - Tile flow began on October 30 after 10.2 cm of water had been applied. Irrigation ceased at 1400 hours and continued the next morning on October 31. Water samples of tile flow were taken on the concentration and recession limbs of the tile discharge hydrograph to determine nutrient concentrations as affected by flow. Samples were analyzed for ammonium-N, nitrate-N, soluble inorganic phosphorus and total soluble phosphorus.

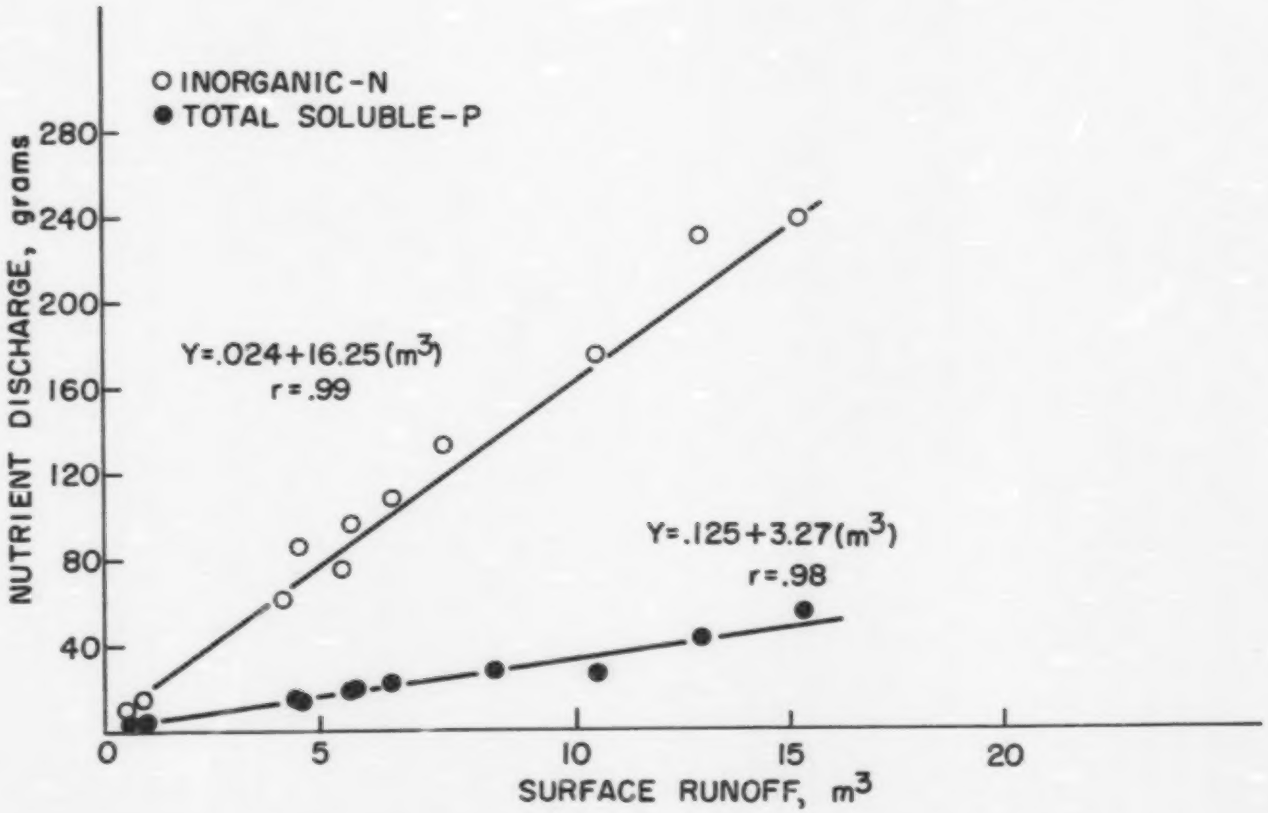

Figure 38. Discharge of inorganic nitrogen and total soluble phoshporus in surface runoff.

Nitrate concentrations in tile effluent showed an expected inverse relationship with flow (Fig. 39 and 40). Ammonium-N concentrations are all less than 0.30 ppm and contribute very little to nitrogen loss from tile effluent.

Concentrations of soluble inorganic phosphorus gave a surprising result. Concentration increased as flow increased then diminished as flow decreased (Fig. 39 and 40). This was rather unexpected because phosphorus in soil solution is controlled either by adsorbed phosphorus or slowly soluble crystalline phosphorus compounds, neither of which should account for this increase in concentration with flow. The irrigation water contained only 5 ppb inorganic phosphorus so this could not explain the result. Chemical reduction of the soil matrix cannot explain this result because there would not be sufficient time or water saturation for the process to occur. More than just the soil chemistry of phosphorus was evidently involved here.

After further study, the answer seemed to be involved with the water movement in the soil to the tile. As tile flow began, the water was primarily from soil solution displaced from soil just above the tile. Flow increases resulted from water moving downward through the plow layer which can maintain a high phosphorus concentration. As more water was applied, the plow layer reached saturation due to the slowly permeable underlying firm till. Water then began to move laterally downslope on the firm till plow layer interface toward the tile. This water that reached the tile also had a high phosphorus concentration and for this reason high phosphorus concentrations resulted at high flow. Some water did enter the firm till and moved slowly toward the tile. When precipitation or irrigation stopped, flow began decreasing but phosphorus concentrations did not drop immediately due to the large component of flow from the plow layer. As flow continued to drop, more of the total flow was from soil solution moving laterally downslope and moving out of the firm till. The low phosphorus concentration solution from the till diluted the higher phosphorus concentration flow from the plow layer and phosphorus concentration then continued to decrease as flow declined. As the soil slowly drained, soil adsorption of phosphorus helped decrease the phosphorus concentration in soil solution which eventually reached the tile. Finally, at low flow only, soil water from the firm till comprised flow and phosphorus concentration dropped to levels near 30-50 ppb P.

Nitrate-N concentrations in tile flow ranged between 22-73 ppm. This is well above the 10 ppm Public Health Standard (18). Nitrate-N loss per day during the time which the tile was flowing is shown in Table 22. Nitrogen loss is related to flow hence most of the loss occurs at peak flows. The loss of soluble nitrogen can be described as a

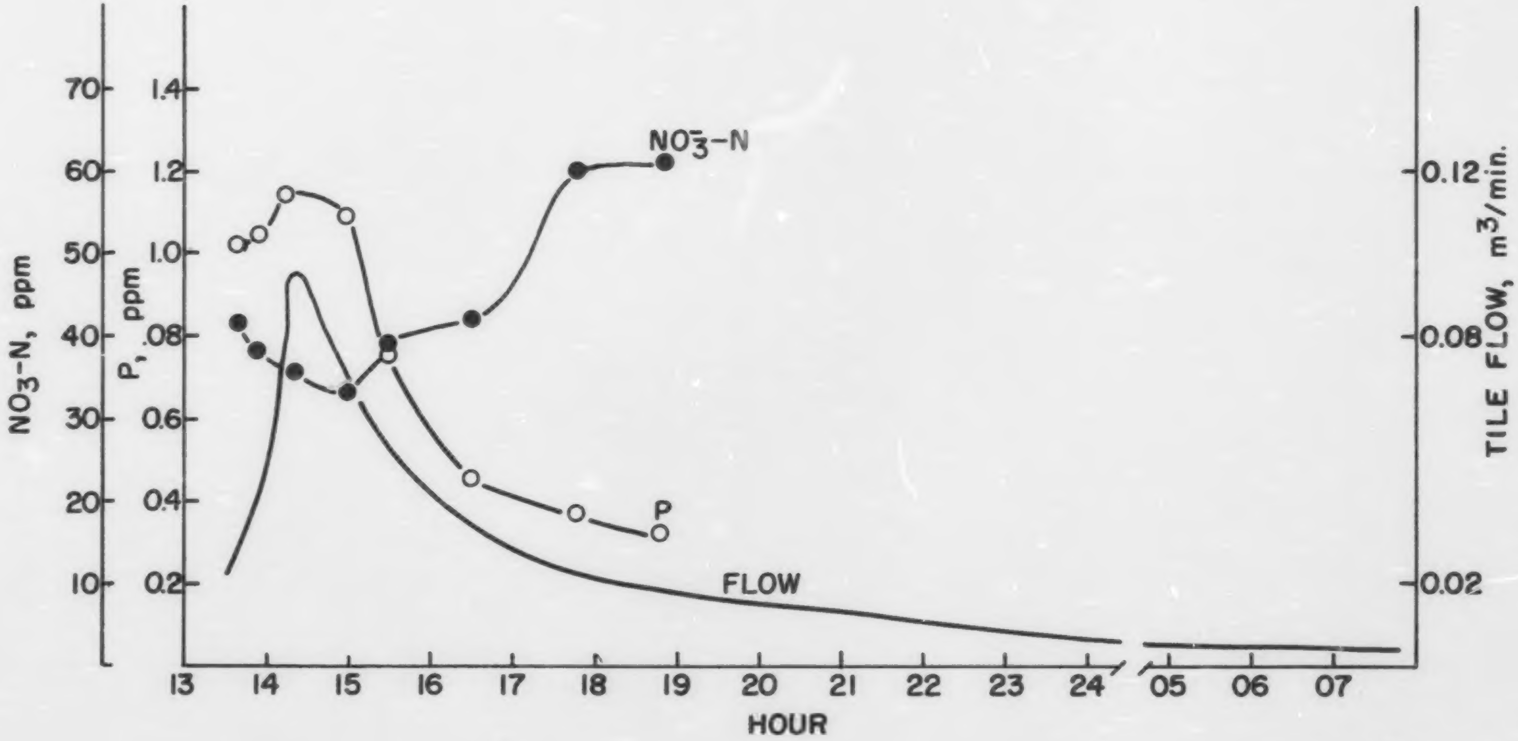

Figure 39. Concentration of nitrate-nitrogen and inorganic phosporus in tile flow. October 30-31, 1973.

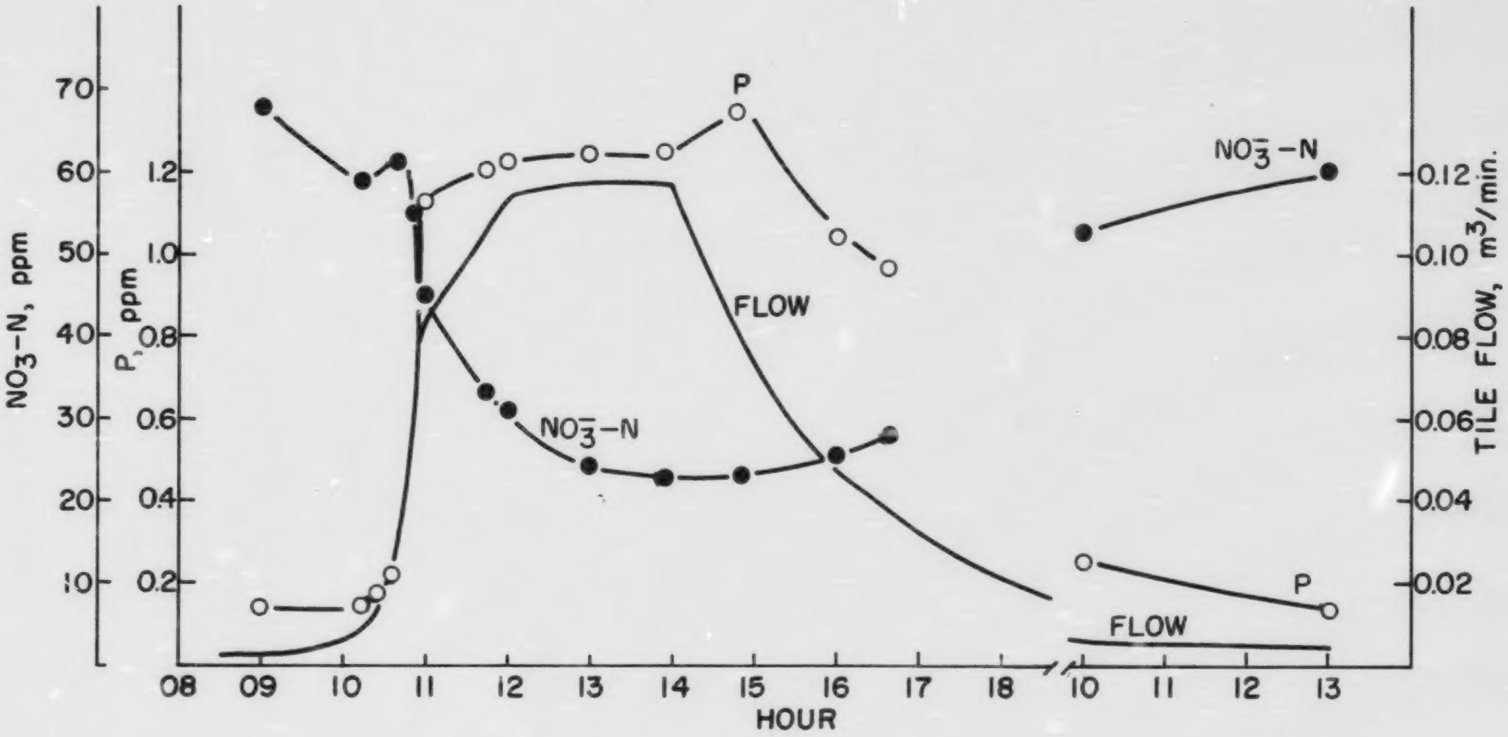

Figure 40. Concentration of nitrate-nitrogen and soluble inorganic phosphorus in tile flow. October 31 - November 1, 1973.

Table 22. NUTRIENT LOSSES FROM TILE FLOW DURING A DRAINAGE EVENT.

	Nitrate-nitrogen	Phosphorus
	-----grams-----	
October 30	735	11.7
October 31	1472	45.3
November 1	538	2.5
2	198	0.4
3	164	0.2
4	87	0.1
5	48	<0.1
6	28	<0.1
Total	3270	60.3

simple function of flow for a given event. Because of leaching of nitrate-N from soil with continued events, the equation for nitrate-N discharge rate as a function of flow would change (Fig. 41). To obtain a more valid estimate of loading that may reflect seasonal variations, more work of this type throughout the year would be required.

Ammonium-N losses were very low. Ammonium is a cation in soil solution and is easily retained by the exchange complex of the soil, hence low concentrations remain in soil solution resulting in minimal losses.

Phosphorus concentration ranged much less than that found in the surface runoff which indicated that the soil is retaining phosphorus from the manure.

Phosphorus discharge for this experiment is shown in Fig. 42. The loading rate is a function of flow, but it is not a simple linear function. The equation which best describes the data is a quadratic. This is not unexpected since we note high concentrations at high flows so most of the loss will be at these values. It can be seen from this figure that at very low flows this equation predicts negative phosphorus loss. This is a limitation of the equation because as long as there is any measurable phosphorus concentration and flow, there will be phosphorus loss. Further work should be done to ascertain seasonal patterns because extension of this model beyond this data is uncertain without further verification.

In summary, it can be concluded that phosphorus losses from the tile will generally be quite small because of the soil's inherent ability to retain phosphorus. Nitrogen losses will always be higher due to the movement of soluble nitrate. Interpretation of concentration must be approached cautiously. Nutrient losses and concentrations must be viewed with respect to the impact they have on the streams within the watershed and not simply by themselves. Soluble inorganic phosphorus and nitrate concentrations in tile effluent also probably do not represent concentrations that would be found in soil solution which continues to seep downward through the soil into groundwater. Phosphorus concentrations would be reduced greatly due to the high phosphorus fixing capacity of subsoils and nitrate could be lost due to denitrification. Data obtained from this type of experiment, however, does provide pertinent information on nutrient losses discharged in a single drain tile from a specific event.

Soil Retention

Soil retention for the purpose of this report can be defined as the

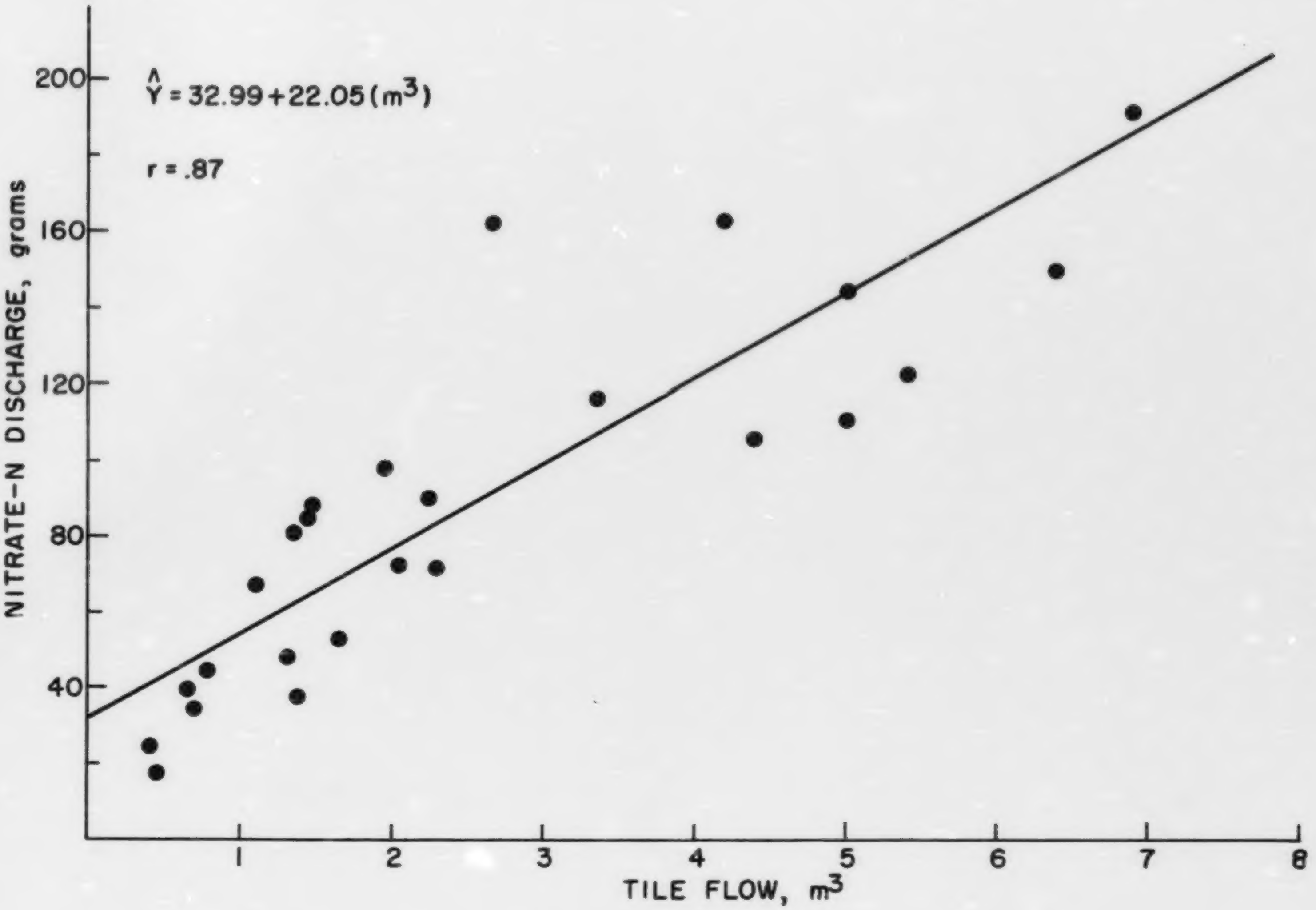

Figure 41. Discharge rate of nitrate-nitrogen in tile drainage.

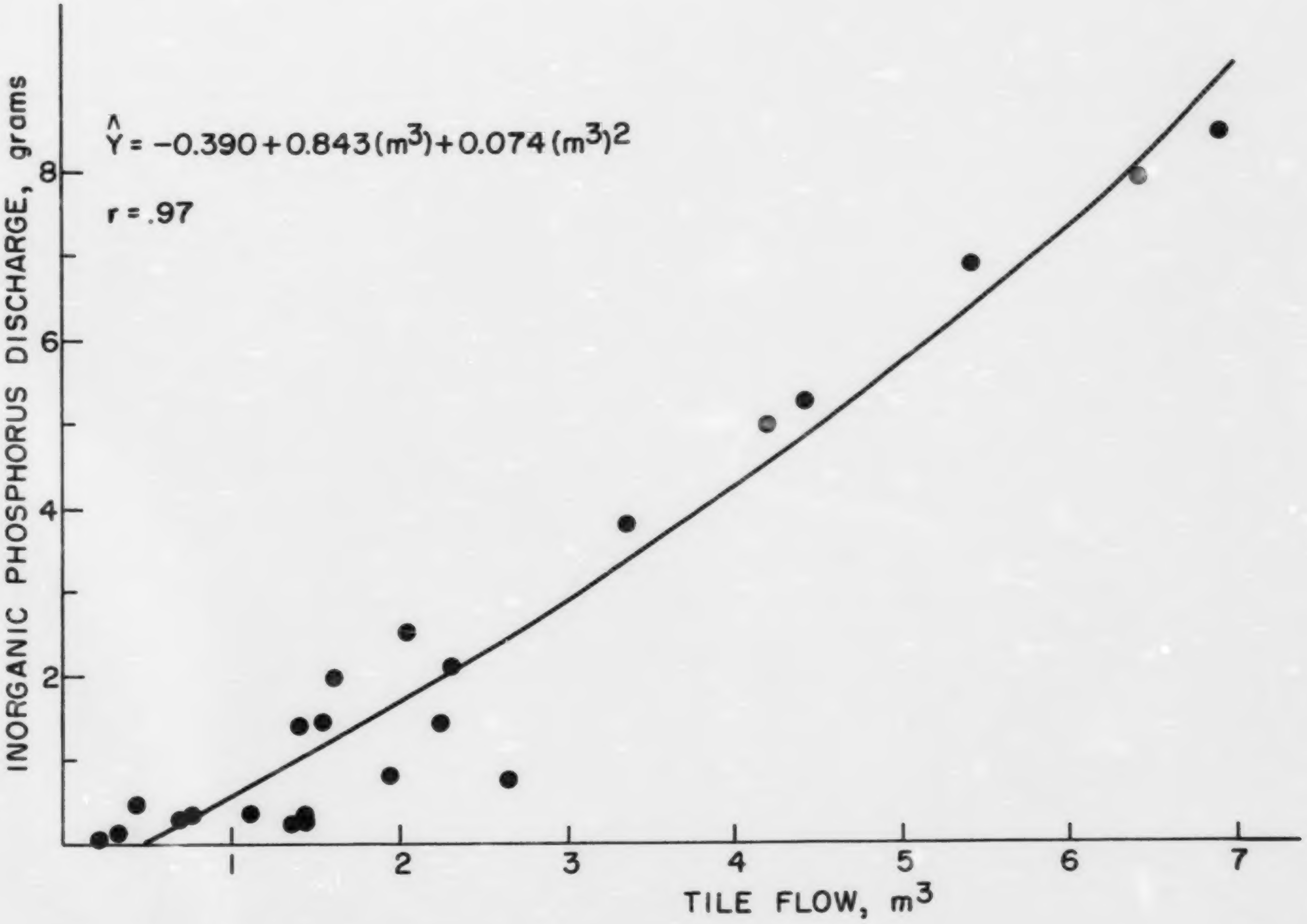

Figure 42. Discharge of inorganic phosphorus in tile drainage.

ability of the soil matrix to retain the nutrients added in animal wastes. It could be thought of as being synonymous with the efficiency at which a sewage treatment plant is operating from the standpoint of nutrient removals. In the case of soils, the concept of nutrient removal *per se* is not valid. Such a concept must be thought of as the ratio of the input of an element to its outflow into the environment. The quantity of material retained by the soil in a given period of time may still be subject to removal in the future by a crop, by water, or by chemical and biological transformations.

The retaining ability of a given soil was measured as it was influenced by the rate and timing of dairy manure disposal. The retention efficiency of nitrogen and phosphorus is expressed as:

$$RE = (\text{input}-\text{output})/\text{input}$$

The inputs of nitrogen and phosphorus were determined from manure loadings based on dry matter contents and nutrient concentrations (Tables A7-A10, Appendix). Outputs were calculated from nutrient losses in both surface water and sediment, and include soluble nitrogen and phosphorus in the solution phase and total nitrogen and phosphorus in the solid phase, over a two year period (1972, 1973). The inclusion of deep seepage outflows was ignored for the purpose of these calculations because chemical and biological transformations (eg, denitrification, additional phosphorus fixation) in the deeper soil profile were not measured. In addition, the 100 t/ha rate of application was not tile drained, making relative comparisons difficult.

Table 23 presents the percent of nitrogen and phosphorus retained by the soil over a two year period of manure inputs. The soil system in itself appeared to be an excellent disposal medium for dairy manure. The retaining efficiencies ranged from 89.2 to 98.7% for the imposed treatments. The lowest efficiency rating appeared for the winter applied 100 t/ha treatment (89.2%). The reason for the lower retention was due primarily to the disposal of this treatment on dense melting snow over frozen soil in 1972 which resulted in excessive losses in runoff.

In general terms, Table 23 denotes that the winter application had a somewhat lower retention efficiency than the spring and summer applications for both nitrogen and phosphorus. Efficiencies for the loading rate are fairly comparable. The higher loading rate (200 t/ha) had the greatest value because it had the largest input of nitrogen and phosphorus. Soil management practice has repeatedly shown an influence on nutrient discharges. A well managed soil in terms of past reincorporation of plant residue, hence improved

Table 23. RETENTION EFFICIENCY OF THE SOIL BASED ON NUTRIENT INPUTS FROM MANURE AND DISCHARGES IN SURFACE RUNOFF AND SEDIMENT. SUM OF 1972 AND 1973.

Time of applic.	Rate, t/ha	Nitrogen, kg/ha In	Nitrogen, kg/ha Out	Retention, %	Phosphorus, kg/ha In	Phosphorus, kg/ha Out	Retention, %
Winter	35	308	13	95.8	85	4	95.3
	100	866	94	89.2	221	22	89.9
	200	1631	24	98.6	388	10	97.4
Spring	35	359	12	96.7	78	3	95.9
	100	1061	26	97.5	218	5	97.5
	200	1851	54	97.1	433	22	95.0
Summer	35	356	17	95.3	90	4	95.6
	100	1074	41	96.2	263	12	95.3
	200	2174	23	98.1	545	7	98.7

MEANS

Time	Winter	95.4	94.8
	Spring	97.1	95.8
	Summer	97.5	97.3
Rate	35	95.9	95.7
	100	94.6	94.2
	200	98.2	97.2
Soil m'gt	Good	97.9	97.8
	Poor	95.7	94.4

soil structure, has shown to be a superior disposal medium than a poorly managed soil.

Soil and Crop Response

Soil Analysis -

A soil sampling program was initiated to determine the influence of dairy manure additions on the nitrogen, phosphorus and organic matter reserve in the soil. Initial soil samples were collected from each experimental plot in the summer of 1971. This was six months prior to the first manure addition. Soil samples were again collected during the summer of 1974, nearly two months after the last addition of manure. Samples were taken from the plow layer (0-25 cm) and analyzed for total-N, available-P and organic matter.

Table 24 presents the 1971 and 1974 soil analysis as well as the changes occurring over the three year period. The values in Table 24 are expressed as percentages. The only significant increase from 1971 to 1974 was for available soil phosphorus at the highest rate of manure application. Although there appeared to be an appreciable increase in total soil nitrogen at the 200 t/ha rate of application, the increase was not statistically different because of inherent variability.

The soil in itself contains a large pool of nitrogen, phosphorus and organic matter. At concentrations of 0.19, .0011 and 3.71 percent, the initial soil quantities of nitrogen, available phosphorus, and organic matter were 6400, 37, and 125,000 kg/ha, respectively. Available phosphorus (not total phosphorus) has a much lower soil reserve because of phosphorus fixation. At such high initial soil contents, it would take tremendous inputs from dairy manure to consistently raise these contents significantly over a three year period.

The smallest increase in soil concentration of these three constituents was noted for the 35 t/ha rate of application. A study of the individual plots receiving this rate of application showed that in 33% of the cases, there was an actual decline in concentration of total soil nitrogen. For the 35 t/ha application rate the decline in available phosphorus and organic matter occurred in 42 and 33% of the cases, respectively. Since almost one-half of the 35 t/ha treatments showed a negative balance with respect to available phosphorus, the overall average for this rate of application also showed a slightly negative increase (Table 24). It is postulated, that after a period of successive inputs, equilibrium will become established, and a positive increase will result.

Table 24. SOIL ANALYSIS OF THE PLOW LAYER (0-25 CM) AS INFLUENCED BY ADDITIONS OF DAIRY MANURE FOR THREE CONSECUTIVE YEARS. VALUES EXPRESSED AS PERCENT.[a,b]

Treatment	Total-N			Available-P, x 10^{-3}			Organic matter, %		
	1971	1974	Gain, %	1971	1974	Gain, %	1971	1974	Gain, %
Time of applic									
Winter	0.196	0.209	6.6 a	1.05	1.52	44.8 a	3.90	4.05	3.8 a
Spring	0.182	0.191	4.9 a	1.18	1.78	50.8 a	3.50	3.70	5.7 a
Summer	0.193	0.202	4.7 a	1.11	1.94	74.8 a	3.75	4.01	6.9 a
Rate, t/ha									
35	0.189	0.193	2.1 a	1.11	1.08	-2.8 a	3.66	3.67	0.0 a
100	0.189	0.195	3.2 a	1.02	1.60	56.9 a	3.80	4.01	5.5 a
200	0.194	0.222	14.4 a	1.20	3.25	170.8 b	3.73	4.32	15.8 a
Soil mg't									
Good	0.193	0.204	5.7 a	1.02	1.78	74.5 a	3.77	4.00	6.1 a
Poor	0.188	0.197	4.8 a	1.21	1.72	42.1 a	3.66	3.84	4.9 a
Average	0.190	0.201	5.8 a	1.11	1.75	57.6 ab	3.71	3.92	5.7 a

[a] Percentages followed by the letter show a non-significant increase from 1971 to 1974 at 5% level.

[b] To convert to kg/ha multiply by 3.36 x 10^6

The mineralization (conversion of organic to inorganic) of organic nitrogen from manure has always been of interest because of its potential soil fertility value. Table 25 shows that the average increase of organic nitrogen in the soil over a three year period was 35%. Based on this average increase, Bouldin* determined the decay series of organic nitrogen over the three year period. The calculated decay series was .55-.30-.16. That is, 55% of the organic nitrogen in the first year is mineralized. The second year, 55% of the organic nitrogen is mineralized from the current input, plus 30% of the residual from the first year. The calculation for the third year manure input is 55% of the current year, 30% of the residual from the second year and 16% of the residual from the first year.

Actual calculations showed the decay series to be a reasonable estimate of the increase in organic nitrogen in the soil after three successive years of dairy manure applications (Table 26). This type of calculation is advantageous in determining how much of the organic nitrogen present in manure will become available for plant growth or as potential soluble nitrogen subject to water transport. Calculations of the mineralization of organic phosphorus as a means of estimating available phosphorus is much more complex. This is due to the fact that available phosphorus can be rendered unavailable because of soil fixation.

Crop Response -

In any land disposal scheme, the response of a growing crop to the addition of dairy manure is very important. Manure management schemes which are detrimental to crop production will never become an acceptable practice in a farming situation.

Corn yields were obtained from each experimental plot for 1972 and 1973. Corn harvesting for 1974 had not been completed at this writing. Yields for both grain and silage are presented in Table 27.

Grain and silage yields did not respond significantly to the timing of manure application (Table 27). It is well understood that maximum yield response is approached when sufficient nitrogen is applied just prior to the maximum demand of the crop. Application of nitrogen made far in advance of crop demand is subject to losses. The reason for the non-significant crop response to additions of manure varying from winter to summer applications may have been due to the loss of

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* Bouldin, D. R. Personal communication, Cornell University.

Table 25. MASS BALANCE OF ORGANIC NITROGEN FROM DAIRY MANURE AS A PERCENT OF THREE SUCCESSIVE YEARLY INPUTS.

Rate, t/ha	Total-N, % 1971	Total-N, % 1974	Increase, kg/ha	Input of organic-N, from manure at 70% of Total-N, kg/ha [a]	Increase of organic-N as % of 3 year input
35	.189	.193	135	335	40
100	.189	.195	200	1000	20
200	.194	.222	950	2000	47
Average	.191	.203	448	1111	35

[a] Approximately 30% of the total nitrogen was inorganic nitrogen.

Table 26. CALCULATION OF DECAY SERIES FOR EACH 100 KILOGRAMS OF ORGANIC NITROGEN FOR A THREE YEAR PERIOD.

Manure added in	Amount decomposed, kg 1972	Amount decomposed, kg 1973	Amount decomposed, kg 1974	Residual at end, kg 1972	Residual at end, kg 1973	Residual at end, kg 1974
1972	55	14	5	45	31	26
1973	-	55	14	-	45	31
1974	-	-	55	-	-	45
Total	55	69	74	45	76	102

% Remaining after 3 years = 102/300 = 34%

Table 27. CORN RESPONSE TO ADDITIONS OF DAIRY MANURE.[a]

Treatment	Grain, kg/ha			Silage, t/ha		
	1972	1973	Avg.	1972	1973	Avg.
Time of application						
Winter	3575	4077	3826 a	22.0	29.3	25.6 a
Spring	3763	4516	4140 a	23.7	29.8	26.8 a
Summer	4014	4516	4265 a	25.3	30.2	27.8 a
Rate, t/ha						
35	2885	3700	3293 a	19.6	27.1	23.4 a
100	4014	4704	4359 b	24.6	31.5	28.0 b
200	5331	5331	5331 c	31.0	33.6	32.3 c
Soil mg't						
Good	4328	4579	4454 a	25.7	30.8	28.2 a
Poor	3261	4140	3700 b	21.7	28.8	25.2 b
Average	3763 a	4390 b	4076	23.7 a	29.8b	26.7

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[a] Means followed by the same letter are not statistically different @ 5% level.

inorganic nitrogen (almost entirely as NH_3) by volatization before soil incorporation. If the manure had been plowed down within hours after the spring application or injected into the soil for the summer application, an additional crop response to nitrogen may have occurred. Immediate soil incorporation far in advance of the growing season (winter and pre-winter applications) would still be disadvantageous because of nitrification. The soluble nitrogen would then be subject to loss by runoff or leaching.

Corn response to the rate of application proved to be significant (Table 27). Increasing rates of manure significantly increased the yields of both grain and silage. Soils that were well managed produced higher yields than poorly managed soils because of a more favorable plant environment.

The response of corn was very well correlated with the amount of nitrogen and phosphorus taken up by the plant ($r = .92$ and $.87$ respectively). Plant uptake is noted in Table 28.

Additional calculations (presented in Tables 29 and 30) were made to determine the percent recovery of nitrogen by corn at each of the three rates of application. Calculations of recovery efficiencies from manure nitrogen alone is impossible owing to the fact that nitrogen is also supplied by rainfall, decomposition of organic matter, etc. and these sources cannot be segregated in the total plant uptake.

The amount of nitrogen made available by the mineralization of organic nitrogen in manure is presented in Table 29 based on the determinations in Table 26. The available nitrogen for crop uptake in Table 30 includes that portion that has been mineralized from manure plus the additional input of 105 kg/ha as noted in the footnote of this table.

The percent recovery of available nitrogen by the corn crop (Table 30) did not differ greatly between the two years but did drop markedly as the rate of application increased. Obviously, the efficiency of utilization of nitrogen decreases with increasing surpluses of available nitrogen. Rates of 100 and 200 t/ha of manure are in excess of the needs for nitrogen by corn. A rate of 35 t/ha in combination with a modest amount of mineral fertilizer (efficiently timed and placed in the soil) could very well result in yields comparable to 200 t/ha of manure. With an increase in yield at the 35 t/ha rate, recovery percentages could be higher since nitrogen uptake for the total crop would increase at a faster rate than the increase in added available nitrogen from fertilizer. Additional data concerning itself with rates of application combined factorially with rates of mineral fertilizer is necessary to achieve conclusive

Table 28. NITROGEN AND PHOSPHORUS UPTAKE BY CORN.[a]

Treatment	Total-N, kg/ha			Total-P, kg/ha		
	1972	1973	Avg.	1972	1973	Avg.
Time of application						
Winter	84	97	90 a	16	18	17 a
Spring	94	105	100 a	19	21	20 a
Summer	105	112	108 a	18	19	18 a
Rate, t/ha						
35	73	84	78 a	15	17	16 a
100	105	113	109 b	18	21	20 ab
200	125	139	132 c	22	24	23 b
Soil mg't						
Good	101	112	106 a	19	20	20 a
Poor	88	99	94 b	16	19	18 a
Average	94 a	105 b	100	18 a	19 b	19

[a] Means followed by the same letter are not statistically different @ 5% level.

Table 29. INPUT AND AVAILABILITY OF ORGANIC NITROGEN FOR THREE RATES OF MANURE APPLICATION.

Rate, t/ha	Input, kg/ha 1972	Input, kg/ha 1973	Mineralized organic-N, kg/ha 1972	Mineralized organic-N, kg/ha 1973
35	111	111	61	77
100	333	333	183	230
200	666	666	366	460

Table 30. PERCENT RECOVERY OF AVAILABLE NITROGEN BY CORN FOR THREE RATES OF MANURE APPLICATION.

Rate, t/ha	Available,[a] kg/ha	Uptake, kg/ha	Recovery, %	Available, kg/ha	Uptake, kg/ha	Recovery, %
	1972			1973		
35	166	73	44	182	84	46
100	288	105	36	335	113	34
200	471	125	27	565	139	25

[a] Additional inputs of available -N in kg/ha = 17 in fertilizer + 11 in rainfall + 10 nonsymbiotic fixation + 67 from soil organic matter = 105 kg/ha. This is in addition to the quantity mineralized in Table 29.

evidence as to the most desirable combination for efficient crop production. Maximizing efficient utilization of plant nutrients automatically minimizes nutrient losses to the environment.

SECTION IV

GUIDELINES FOR LAND APPLICATION OF MANURE

FUNDAMENTALS

General

Land represents not only an appropriate disposal medium for manure but also an opportunity to manage wastes with minimum adverse environmental effects. Chemical, physical and biological properties of the soil should be utilized as an acceptor for residues with minimum unwanted effects to the crops that are to be grown, as well as to characteristics of the soil and to the quality of the ground water and surface runoff.

The soil system is a complex of chemical, physical and biological properties. Such properties determine, to a large extent the suitability of the soil for growing plants. They also determine suitability for manure disposal. Considerations such as topography and climate may determine the practicability or the extent to which any particular soil can be utilized. Soil properties that are important for growing plants determine the fate of waste materials applied to or incorporated in the soil. Since there are many soil types, varying in characteristics, a knowledge of some of these more important characteristics will permit a more judicious use of the soil. Soils will continue to be used as a 'sink' for waste disposal and knowledge of soil properties can be used to establish safe loading limits of the soil. Unnecessary pollution of groundwater, streams and lakes can occur because soil properties are not known or understood.

Soils vary greatly in their physical and chemical properties. They are classified according to these properties. By knowing some important properties of the soils in question, they can be grouped into a few meaningful categories. These provide a valuable guide for waste disposal purposes. Such information is contained in soil survey reports. The layman may find the advise of a soil scientist to be valuable when attempting interpretation of such soil survey reports. These soil survey reports can usually be obtained locally through the county Agricultural Agent or the local soil conservation district office. Frequently, these local offices are combined with the local office of the U.S. Soil Conservation Service. Complete soil survey reports may also be purchased from the Superintendant of Documents, Government Printing Office, Washington, D.C. Frequently, individual copies for specific counties can be obtained free of charge from the State College of Agriculture or the office of the local Congressman.

Soil Chemical Properties

Soils of the humid temperate regions have a net negative charge which permits the soils to retain or hold the positively charged ions, thus providing a reservoir or storehouse for plant nutrients. The extent of this ability to hold cations is termed the cation exchange capacity. Cations are held by this exchange complex. Common cations held in this manner are calcium, magnesium, potassium, ammonium, sodium, and aluminum. The source of these cations can be any one or a combination of the following: the results of mineral weathering, organic matter decomposition, applied manure, or fertilizer.

Negatively charged anions such as nitrate are not affected by the temperate region soil charges and move freely with soil water. Nitrates moving beyond the rooting depth of crops or across the soil surface can affect water quality. Nitrogen and phosphorus will be emphasized in this discussion because they are considered to be major sources of potential water quality problems. They are found in large quantities in animal wastes.

Soil Physical Properties

The physical properties of the soil determine the rate at which water moves into (infiltration) and through the soil (leaching or percolation). Soil texture and structure determine these rates. Texture refers to size groupings of individual particles such as sand, silt and clay. Structure refers to the grouping of the individual particles into aggregates. These factors determine the porosity or pore size distribution in soils which is important to the transmission rate of water through the soil. The movement of soluble nutrients such as nitrate nitrogen occurs more readily in sandy soils than in silt and clay soils because the water holding capacity is greatest for clay soils, less for silts and least for sands.

Other physical properties of importance when considering land for waste disposal include location of dense subsurface layers, seasonal water tables, topography, and degree of natural and artificial drainage. Anything that restricts downward water movement and causes oversaturation of the surface soil can result in excessive surface runoff. Adequate infiltration of water and sufficient soil aeration are essential for crop growth and microbial activity for the breakdown of animal wastes.

Nitrogen and Phosphorus

A major portion of the nitrogen in manure reaches the soil in the organic and ammonium forms. By microbial activity, the organic forms are converted to the ammonium form. Ammonium ions (NH_4^+) can be absorbed on the exchange sites (cation exchange) of the soil. Hence, their mobility is reduced. Ammonium ions are also subject to nitrification. The usual end product is nitrate (NO_3^-) which is soluble and mobile. Nitrate is easily lost by runoff or by leaching to the deeper depths of the soil. At these deeper zones of the soil profile, some of the nitrate can be reduced, usually to elemental nitrogen (N_2) if denitrifying conditions exist and lost to the atmosphere by volatilization.

Applied inorganic phosphorus is quickly converted to water insoluble forms. Fixation of phosphorus as relatively insoluble compounds effectively reduces the concentration of phosphorus in solution. Soil erosion processes may move substantial amounts of phosphorus as constituents of soil particles and organic matter.

Water Movement

Management practices must center around not only soil characteristics but the climatological patterns that are prevalent in a particular area.

Climatological patterns in the United States are surprisingly consistent from one year to the next. Perhaps the most important aspect of the yearly climatological cycle is the relationship between streamflow, precipitation and evapotranspiration. Figure 43 is an illustration of this relationship for western New York. The general relationship will be similar in the north central and northeastern states, although the actual quantities will vary between regions and years in response to local climatic variation. Regardless of the absolute values for a particular region, the basic concepts given by Figure 43 will apply.

When evapotranspiration exceeds precipitation in the early summer, crops become dependent on water in the soil reservoir. Under 'average' conditions, there is not a surplus of water and nutrient movement is localized. Surface runoff, however, can occur anytime that the intensity of a rain storm exceeds the infiltration rate or percolation rate of the soil. During the late summer and early fall months, precipitation begins to exceed evapotranspiration, but there is generally no appreciable increase in water movement out of the soil profile because of soil water recharge.

At the onset of the winter months, precipitation continues to exceed evapotranspiration and the capacity of the soil water reservoir becomes exceeded. When the soil becomes saturated, excess water is available for percolation through the soil profile to underground aquifers. Surface runoff is most prevalent because of the restrictions of water transmission through the soil. Continued ground water recharge as well as surface runoff causes a rise in streamflow. The period when the largest flow of water is likely, and hence, the period of major nutrient movement is during periods of high stream flow. For the northern states, this occurs in late winter and early spring runoff.

The management of land disposal of manure must be oriented around the practices that will best prevent sediment and nutrients from being carried by runoff and nutrients from being leached out of the 'active' portion of the soil profile.

Nutrient Management

A system of recycling for plant nutrients cannot be maintained unless these added nutrients are utilized by a growing crop. The greater the capacity of a given crop to reduce nutrient losses by reducing erosion and utilize the constituents in manure, the greater the amount of manure that can be added. It is well known that the closer plant nutrients are applied to the time of maximum demand by a crop, the

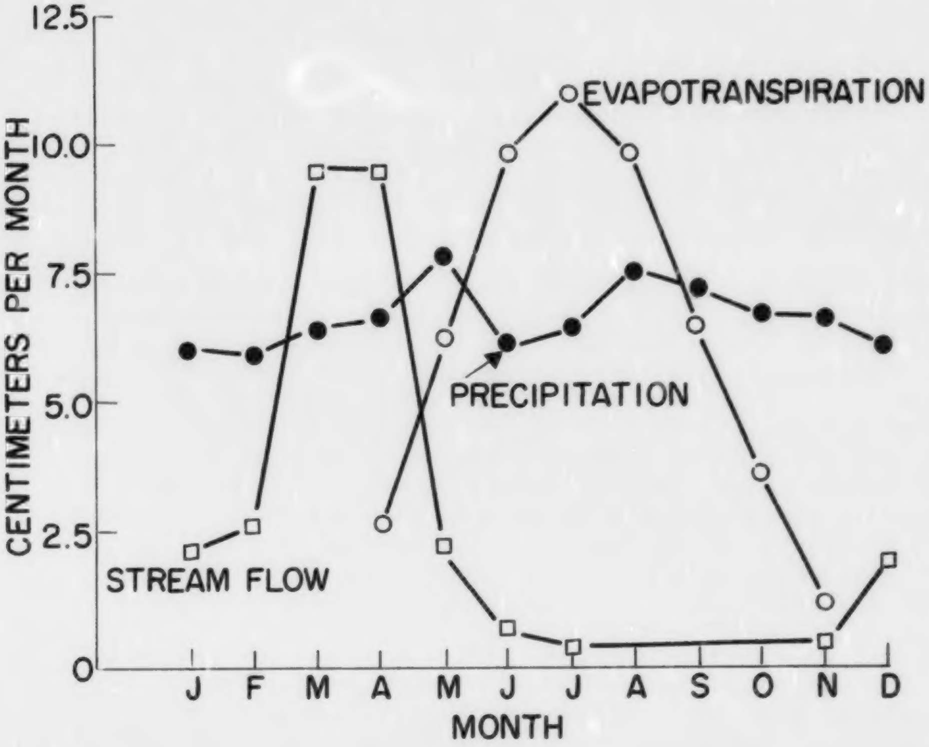

Figure 43. Estimated evapotranspiration in the Erie-Niagara Basin, normal rainfall at Lockport, N.Y., and stream flow of Little Tonawanda Creek at Linden, N.Y. (30).

greater will be the efficiency of utilization. This will in effect, insure that the soluble constituents do not remain in the soil for an extended period.

In the north central and northeastern states, there are few actively growing crops from early fall until late spring. This time coincides with increased water movement. Consequently, manure additions in the fall and winter may create an excess of plant nutrients that will become subject to transport. Once these nutrients are either transported off of the field or below the root zone, they are lost from the cyclic system, and nutrient enrichment of waters may occur. Manure applications made during the late spring and summer months, after maximum runoff and leaching have occurred, allow for more efficient utilization of nutrients by plants. Disposal of manure on the land in late spring is not always easy to achieve. It is difficult to apply a substantial percentage of the manure just prior to planting a crop, especially if daily spreading is practiced.

Nitrogen recycling appears to be the prime objective because of its solubility which makes it easily subject to transport from the disposal area. Manure application rates to the land should closely relate to the estimated annual crop usage of nitrogen. It is assumed that if nitrogen movement is controlled, conservation of other constituents in manure will follow.

Undesirable losses of nutrients to surface and groundwater will be reduced by well planned manure-soil-crop management practices. Animal wastes should be utilized as a primary source of fertilizer. Mineral fertilizers should be used only to make up remaining deficiencies.

LAND APPLICATION

When manure is spread on the land, the following conditions need to be met: a) surface runoff should be controlled; b) the soil and vegetation should serve as a 'sink' for nutrients contained in the manure so that surface and groundwater are not excessively enriched; c) odors should be controlled. If these conditions exist, the resulting system allows the nutrients from the manure to be recycled to crops to animals and to crops again with minimum losses.

Principle pollution potentials of manure are associated with: (a) inadequate manure storage facilities, and (b) excessively high rates of manure applications. Excessive losses of manure and/or its soluble constituents can result in: a) nutrient enrichment and oxygen depletion of water courses; b) nitrogen enrichment in potable water supplies; and c) the possible transmission of disease.

Conservation Practices

Many nutrients in manure can be lost between the time of deposition by the cow and the time they are available to the growing plant.

Some of these losses are:

(a) Volatilization of nitrogen in the form of ammonia or denitrification products. The denitrification mechanism does not contribute significantly to local water pollution problems.

(b) Surface runoff losses of nutrients as contained in the liquid fraction or sediment.

(c) Leaching losses of soluble nitrogen as water moves through the soil profile. Eventual recharge of the underground reservoir may become enriched with soluble nitrogen.

Land application schemes for the disposal of animal wastes must contain sound management practices to prevent the loss of nutrients via surface runoff and leaching. Diversion of surface water from areas outside the cropped region is an important control measure. Frequently, surface water from upper-lying non-cropped areas can be intercepted above the spreading field and delivered to a suitable outlet. Technical assistance with soil-water management problems and control practices are available through the Soil Conservation Service. Advice can also be obtained from the local county Extension Service.

Proper Management Techniques

Most dairy manure in the north central and northeast region is handled either as a solid or semi-solid. The manure may or may not contain bedding and will not have any extra liquids added. Application is usually done with a conventional manure spreader on a daily basis. Liquid manure contains a higher percentage of water and is usually stored until disposal is convenient. Application methods include surface spreading, plow cover furrow methods and irrigation. Irrigation with liquid manure is still in the development stage and consists of a storage area, pump and necessary pipe to convey it to the disposal area. It may have only limited use in some areas, because of odors and soil topography.

When a choice is available, manure should be spread on fields that are: (1) well and moderately well drained; (2) are the least sloping; and (3) contain the greatest amount of vegetation.

Manure should always be spread as uniformly as possible. This uniform coverage allows a given amount of manure to come into contact with the largest surface area of soil and/or vegetative cover. Liquid manure spread from storage facilities should be incorporated immediately with the soil especially where odors may effect nearby residences. Incorporation with the soil not only greatly reduces odor, but also the chances of manure movement by surface runoff. Incorporation may be impractical except where soil injection systems are used, or applications made prior to spring or fall plowing.

Liquid and semi-liquid manure requires somewhat more careful management than does solid manure because it is more susceptible to runoff.

Timing of Application

The best time to dispose of manure is when it is most likely to remain where it has been applied. Common cropping practices and weather conditions make this time appraisal somewhat difficult. The following management practices will help to minimize the movement of manure by runoff:

Fall -

Apply manure to those fields containing the greatest amount of vegetation or crop residue. A hayfield that will be plowed the following spring would be an excellent choice.

Secondary choices would be those with somewhat less crop residue such as a corn field, small grain stubble or fields grown up to weeds and small brush can also be used.

Fields that are to be fall plowed make excellent choices for manure disposal. Immediate plow down is advantageous because: a) the soil can immobilize some of the nutrients contained in the manure; b) manure is not exposed to surface waters during fall, winter, and spring runoff. Areas that are to be plowed for non-leguminous crops (corn, etc.) the following spring should have precedence over fields that will be planted to leguminous crops (alfalfa, etc.). The former will utilize nitrogen more efficiently.

Winter -

The major problems with winter spreading are frozen soil or deep snow which may make fields inaccessible. Frozen soil is relatively impervious to water, making runoff eminent during thaws, which is compounded if accompanied by rain.

Accumulated manure from storages should be spread in November or early December before the beginning of continuous snow cover. If a snowpack or an ice sheet develops later, it will be over, rather than under, the manure. This will provide some protection from runoff. Ideal disposal areas would be fields that contain vegetation to be plowed in the spring (sod, stubble, etc.).

For daily spreading programs, the distance to and accessibility of fields to be used for winter spreading should be considered. Areas having limited access should be used early in the winter. Easily accessible land can be used during periods of deeper snow cover. This schedule will help to avoid overloading fields close to the barn when the snow is deep.

Spring -

Manure used in a daily spreading operation should be applied to fields that are to be plowed. Stored manure should be applied and plowed down just prior to spring planting. This reduces the time period during which soluble nutrients are subject to leaching. A growing crop can utilize these nutrients, reducing losses to the environment.

If manure is spread on meadows, a grass hayfield or a leguminous hayfield in its last year of production would be appropriate. The rate of application should be low enough so as not to interfere with the first cutting of hay.

Summer -

Summer applications may be made on meadows, wheat and oat stubble, unused pasture areas, weedy non-crop areas, or fields with light brush growth.

Rates of Application

The suitable rate of manure application is determined by the ability of the soil/crop combination to immobilize and utilize the nutrients in manure. The greater the crop requirements for plant nutrients, the greater the amount of manure that can be applied, however, soil characteristics may be the limiting factor. The applied nutrients must remain on or in the soil long enough to benefit the crop. Soil depth, drainage and slope are important considerations.

The suggested maximum application rate is 67 t/ha/yr (30 t/acre) and is based on the best available knowledge at this time. The maximum rate is determined by the approximate amount of nitrogen that will be available the first year assuming a 0.5% N content of the fresh weight. Additional suggested rates, if the maximum is not desired, for several crops are as follows:

Crop	Rate, t/ha/yr
Corn	45
Grass-hay	35
Oats	20

Additional starter fertilizer at planting time may be necessary and it is suggested that local University recommended rates for fertilizer in combination with manure application be consulted.

Tables 31, 32 and 33 present rates depending on various soil characteristics. Rate calculations should be rounded to the nearest 10 t/ha.

Table 31. SUGGESTED RATES OF DAIRY MANURE APPLICATIONS FOR PLOW-DOWN OR INJECTION (APRIL 1 - SEPT. 1) AS A PERCENT OF THE MAXIMUM RATE.

Slope, %	0 - 3	3 - 8	8 - 15
Rate	100	100	100

Table 32. SUGGESTED RATES OF DAIRY MANURE APPLICATIONS FOR SPRING AND SUMMER TOPDRESSING (APRIL 1 - SEPT. 1) AS A PERCENT OF THE MAXIMUM RATE.

Slope, %	0 - 3	3 - 8	8 - 15
Rate	100	50	30

Table 33. SUGGESTED RATES OF DAIRY MANURE APPLICATIONS DURING FALL AND WINTER MONTHS (SEPT. 1 - APRIL 1) AS A PERCENT OF THE MAXIMUM RATE.

Soil depth to bedrock, cm	50 - 100			0 - 50		
Slope, %	0-3	3-8	8-15	0-3	3-8	8-15
Drainage						
Excessive (sand or gravel substrata)	50	50	30	-*	-	-
Well Moderate	100	50	30	60	30	20
Somewhat Poor Poor	50	25	15	30	15	10

* Rarely occur.

LEGEND

1. Slope
   a. 0 - 3% - Level to nearly level.
   b. 3 - 8% - Nearly level and gently sloping to sloping and strongly sloping.
   c. 8 - 15% - Strongly sloping to moderately steep.

2. Drainage
   a. Excessive - Water is removed from the soil rapidly to very rapidly
   b. Well - Water is removed from the soil either rapidly or readily
   c. Moderate - Water is removed from the soil somewhat slowly. Soil profile is wet for a small but insignificant part of the time.
   d. Somewhat Poor - Water is removed from the soil slowly enough to keep it wet for significant periods but not all of the time.
   e. Poor - Water is removed from the soil so slowly that it remains wet for a large part of the time. The water table is commonly at or near the surface most of the year.

SECTION V

AN ECONOMIC IMPACT AND WATER QUALITY EVALUATION OF CERTAIN PROPOSED ANIMAL WASTE DISPOSAL LEGISLATION WITH RESPECT TO DAIRY FARMS

INTRODUCTION

All agricultural operations have an impact of some significance on quantity and composition of ground and surface water leaving the area. There are numerous alternative diets and numerous agricultural production schemes to supply these diets available to the American people. The specific alternatives we have investigated here are those concerned with milk production.

Major attention is devoted to the nutrient losses associated with the disposal of the dairy manure in various crop production schemes associated with production of the feed for the dairy cows. In effect we wish to combine the crop production and manure disposal aspects of milk production so as to keep the costs of milk production at a level which ensures its availability to all income groups and yet not degrade water quality to an unacceptable level. As a first approximation, the two factors, cost of milk and nutrient addition to water, are inversely related and more or less continuous functions. That is, there are essentially an infinite number of management schemes which produce a corresponding number of paired milk production costs and nutrient losses such that generally the production costs of milk will increase as restrictions are placed on the amount of nutrients which can be lost in ground and surface water leaving the dairy farms.

Most of the present legal procedures are of very little value in the control of the downward movement of contaminants through the soil and into the groundwater. Proof of the source of the contaminant, and proof of the causative negligence, is extremely difficult to establish for most of the materials commonly involved in agricultural pollution by runoff or through groundwater. It is no less desirable that this type of pollution should be controlled. Up to the present time, however, there has been little agreement on the details of the controls which might be suitable. Attempts are being made to standardize and put such controls on a quantified basis, but the most common approach at the present time is to leave the decision with some appropriate authority as to whether a farmer's practice or proposed practice is acceptable or not.

Consideration of the problem of writing legislation to control agricultural pollution should include the points of view of the farmer, the legislator, the administrative agency and the environmentalist. For the purposes of this study, there are the following primary objectives of legislation:

1. To prevent or reduce pollution - biological, chemical, visual.
2. To conserve material nutritional to plants and animals.
3. To encourage the formation of stable soil physical conditions.
4. To maintain favorable relationships between farmers and the public.

These objectives might be achieved by a combination of one or more of the following approaches:

1. To prohibit certain practices under conditions which make them undesirable, as would be the case if they violated any of the four objectives listed above.
2. To make it possible to easily identify those with the potential to cause the problems which are to be controlled so that compliance with the law can be readily established.
3. To make compliance with the law desirable and attractive to the farmer in order to reduce the need for enforcement.
4. To make the farmer responsible for proving compliance with the law.

It is probably not desirable to construct rigid regulations which force a farmer to adopt methods and procedures which are not optimal for his operation. There are many ways to modify farm practices to achieve the objective of reduced pollution. Farmers should be encouraged to use all the ingenuity at their command to achieve these objectives, rather than to simply comply with a uniform set of conditions prescribed by a Pollution Control Board*.

---

* Dr. S. R. Aldrich, personal communication, Illinois Water Pollution Control Board, 1972.

It is not the intention of this study to enter into the arguments as to whether or not agricultural practices, and animal wastes in particular, are a major contributor to pollution. It has been established that there is not only a potential for pollution, but that farm animal wastes do frequently contribute to lower water quality and odor and fly problems (5, 16). This section is concerned with the identification and selection of the type of legislative controls which might, in the foreseeable future, be enforced.

Many of the assumptions and methods of approach used to formulate the linear model was developed from the findings of the three year study dealing with land application. This phase has been discussed in Section III.

Those factors which legislation may attempt to control can be briefly summarized as follows:

1. Soluble organic material capable of causing a lowering of dissolved oxygen levels in water on microbial degradation. This oxygen depletion may cause, and has caused, fish kills.

2. Nitrogen, both inorganic and organic forms which can be released as inorganic nitrogen after degradation. Ammonium and nitrate nitrogen fertilize undesirable growths of aquatic flora, and, with nitrite, can be toxic to man and animals when ingested in large enough quantities.

3. Phosphorus, both inorganic soluble forms and organic phosphorus which may be released on degradation. Phosphorus is necessary for the growth of aquatic flora.

4. Suspended solids. Sediments cause siltation of waterways and sludge banks contain organic solids which can xause oxygen depletion and the production of noxious gases on decomposition.

5. Volatile materials such as hydrogen sulfide and organic compounds which cause undesirable odors.

6. Color and turbidity of water causing decreased aesthetic values.

7. Pathogenic organisms such as bacteria, viruses and parasites in various forms and life stages which may be infectious to humans or other animals or both.

8. Pests such as rodents, flies and mosquitoes.

9. Unsightly appearances which detract from rural amenities.

The summary above includes many items which are common to the undesirable waste characteristics of any source such as industry and municipalities (6). Some, such as items eight and nine, are frequently, but not uniquely, a problem with a large scale animal operations (16).

A review of the available literature on existing and proposed laws and guidelines has been made. It is possible to discern a number of specific approaches to the problem of controlling the problems listed above. The fact that many of these approaches are still proposals and have not yet been included in actual legislation should not detract from the need to give them adequate consideration. If public pressure continues to increase, and if officials respond by becoming bolder, these proposals will undoubtably be given greater attention and possibly enacted into law. Possible approaches may be summarized and listed as follows:

1. To restrict the amount of manure which can be spread on a unit of area in one year.

2. To restrict the quantity of nitrogen and/or phosphorus which may be spread on a unit of area in one year.

3. To restrict the spreading of manure to soils which are not excessively permeable or excessively impermeable.

4. To restrict the spreading of manure to flat or only gently sloping fields.

5. To restrict the spreading of manure to areas greater than some acceptable distance from surface water capable of leaving the operator's property.

6. To restrict the spreading of manure to certain times of the year.

7. To restrict the spreading of manure to areas greater than some acceptable distance from dwellings and areas to which the public have access.

8. To require that a certain minimum land area be owned or controlled by the farm operator according to the quantity and type of animals kept.

9. To require that any form of manure disposal, other than land application, meet the same controls and standards as those required for industrial or municipal effluent disposal.

10. To require that treatment, handling and storage of manure be such that no disease, odor, insect or rodent nuisance is caused. Note: In the above list, it is assumed that "manure" refers to fresh, stored, or treated animal wastes.

Just what the various distances, permeabilities, slopes and application rates should be for use with the ten proposals listed above is far from certain. It must be kept in mind that the purpose of the controls is to meet the primary and secondary objectives listed previously. It may be argued that there is insufficient data at this time to allow any decisions to be made. While this may be partially true, it must be remembered that this same lack of data has not prevented many government agencies from issuing guidelines to accompany approval certificates for livestock operations.

It remains the purpose here to estimate some of the values which might be used with each of the proposed regulations. These will enable a set of restrictions to be outlined which will represent a range of legislative severity. Existing and proposed regulations and several examples are given in Tables 34 and 35.

Table 36 lists hypothetical controls at two levels. These levels approximate what can be considered an "intermediate" degree of pollution control, and a "high" degree of pollution control.

It has been the intention in presenting this discussion to prepare the reader with the background needed to interpret Table 36.

Briefly, the rationale behind these hypothetical controls is as follows (numbering corresponds to numbered sections of the table):

1. A limit of 112 Met. tons/ha (50 tons/acre) of manure is likely to avoid gross pollution by runoff and aesthetic impairment. At restriction level 2, however, the intention is to limit manure to a level where there is little possibility of there being excess nitrogen for excessive leaching.

2. The fertilizer limits correspond to the manure nutrients in (1) above, assuming approximately 70% manure N available or mineralized over a period of years, the remaining N being assumed to be volatilized. At restriction level 2, there is a lower denitrification allowance because of the lower levels of undecomposed organic matter where there is no manure application.

Table 34. SUMMARY OF EXISTING AND PROPOSED STATE REGULATIONS TO CONTROL LIVESTOCK RELATED POLLUTION.[a]

Situation type		
1	Existing laws requiring registration of certain livestock operations.	Arizona, Colorado, Florida, Indiana, Iowa, Kansas, Minnesota, Nebraska, North Dakota, Oklahoma, South Dakota, Texas [b,c,d]
2	Existing laws to control wastes from livestock operations but with no registration requirement.	Illinois, Ohio, Wisconsin [b,c]
3	Registration requirements for waste discharges.	Maine, Massachusetts, New Jersey, New York, Pennsylvania, Rhode Island, Florida [c]
4	Discharge requirement without registration.	Almost all states, other than those listed under 3 above.
5	Waste disposal administrative codes.	Arizona, California, Colorado, Indiana, Iowa, Kansas, Maine, Missouri, Massachusetts, Minnesota, Nebraska, Oklahoma, Texas [c]
6	Other proposals.	Unknown total number.

[a] Not necessarily complete as these regulations are constantly changing.

[b] Lutz, (47)

[c] Johnson *et al.*, (39)

[d] Schwiesow, (62)

Table 35. EXAMPLES OF EXISTING AND PROPOSED STATE REGULATIONS TO CONTROL LIVESTOCK RELATED POLLUTION.[a]

Situation type	State	Application criteria	Conditions
1	Iowa[b]	1. >1,000 head of cattle in confinement. 2. If runoff contributes to a watercourse draining an area of 1300 hectares or more and confinement less 0.61 m (2 ft) per head of cattle in the confinement from this water course. 3. If runoff from confinement lot or from retaining lagoon flows into a drain conduit, any type of well, or into a sinkhole.	Retention ponds and terraces must be able to contain at least 7.6 cm (3 in.) of runoff water from all waste contributing areas. Settling basins must be provided for solids separation before runoff reaches retention ponds. Waste treatment may be permitted with permission of Dept. of Health. Retention ponds must be emptied as soon as possible after runoff.
		Applicable to any operation where there are at least 100 head of cattle, or where density is greater than 1 animal per 56 m^2 (600 ft^2)	Proposed: Approval of waste disposal practice based on information supplied as to soil types, use of land between confinement and stream, slope of land, infiltration rate, control of waste discharges in relation to stream flow and distance to dwellings. Wastes may be spread on land surface, irrigated, or mixed into soil in such a way as to prevent runoff of wastes. All other methods subject to individual approval.

Table 35. (Continued) EXAMPLES OF EXISTING AND PROPOSED STATE REGULATIONS TO CONTROL LIVESTOCK RELATED POLLUTION.[a]

Situation type	State	Application criteria	Conditions
3	Florida[c]	Any livestock or animal waste abatement installation considered a potential source of water pollution, and all firms with waste systems handling more than 227 kg BOD_5 (500 lbs)	Subject to approval.
5	Maine[d]	Applies to: Total annual animal and poultry manure production after removal from the barn or storage area. Covers: Manure use by crop production; disposal of excess by land spreadings, stockpiling, burying in landfills, composting, lagooning, irrigation, drying.	1. No spreading on frozen[e] ground. Exception in upland soil with less than 3% slope in which case limit is manure or waste with nitrogen content of 280 kg/ha (250 lbs/ac). 2. Tabulated nitrogen applications for each soil type in the state are limit for total nitrogen including fertilizer. 3. No waste less than 7.6 m (25 ft) from water body. 4. No waste less than 30 m (100 ft) from spring, well or lake. 5. No spreading near lakes if runoff probability high. 6. No spreading on slopes greater than 25%.

Table 35. (continued) EXAMPLES OF EXISTING AND PROPOSED STATE REGULATIONS TO CONTROL LIVESTOCK RELATED POLLUTION.[a]

Situation type	State	Application criteria	Conditions
5	Maine (cont'd)		7. No spreading in depressions which carry water during snow melt or heavy rainfall. 8. Tabulated maximum nitrogen applications to crops from fertilizer or waste (crop must be harvested) - example corn - 280 kg/ha (250 lbs/ac); oats - 56 kg/ha (50 lbs/ac) etc. 9. No dumping on floodplain unless waste is plowed under. 10. Dumping may be done at rates up to 673 kg/ha 600 lbs/ac) of nitrogen if a crop is removed. Otherwise limit is 561 kg/ha (500 lbs/ac) nitrogen. 11. Stockpiling only allowed on certain soils. 12. Stockpiled wastes must be removed within one year. 13. Stockpiling of wastes cannot be on slopes greater than 8% or within 91 m (300 ft) of water bodies, streams, wells or springs.

Table 35. (continued) EXAMPLES OF EXISTING AND PROPOSED STATE REGULATIONS TO CONTROL LIVESTOCK RELATED POLLUTION.[a]

Situation type	State	Application criteria	Conditions
5	Maine (cont'd)		14. There are many conditions relating to composting, burying, etc. 15. Every soil in the state has been classified and limits applied for each of the activities listed above.
6	New York[f] Proposals	Guidelines	Limit liquid and solid manure applications to nitrogen need of crop. Semi-solid manure (13-18% dry matter) limit 67 Met. ton/ha (30 tons/ac). Spring or summer plowdown - 100% of maximum rate; spring and summer top-dressing - 24% to 100% of maximum depending on soil slope; fall and winter applications - 8% to 100% of maximum depending on soil slope, depth and drainage class (given in a table).
6	Illinois[g] Proposals	Legislation	Nitrogen - 50 kg/ha (50 lbs/ac) in fall; 34 kg/ha (30 lbs/acre) in fall, on fall seeded crops only, on sandy soils; none on slopes greater than 5% when frozen; maximum rates at other times of year depending on crop and soil type, and whether irrigated or not.

Table 35. (Continued) EXAMPLES OF EXISTING AND PROPOSED STATE REGULATIONS TO CONTROL LIVESTOCK RELATED POLLUTION.[a]

Situation type	State	Application criteria	Conditions
6	Illinois (cont'd)		Phosphorus - none if slope greater than 5% and soil frozen; 56 kg/ha (50 lbs/acre) limit on organic soils (soils with greater than 20% organic matter). Manure - no spreading on soils with slopes greater than 5%, within 201 m (650 ft) of a stream or lake, when soil is frozen; none in natural drainage or waterways. Other limits for sludge and effluents.

[a] Not necessarily complete as these regulations are constantly changing.

[b] Agena, (2)

[c] Johnson _et_ _al_., (39)

[d] Maine Special Statewide Committee.

[e] Undefined.

[f] Klausner, (43)

[g] Anonymous, (1)

Table 36. SUMMARY OF POTENTIAL WASTE DISPOSAL REGULATIONS AT TWO LEVELS.

Parameter	Restriction level 1 [a]	Restriction level 2 [b]
1. Application rates of manure	112 Met. tons/ha (50 tons/acre) (unless covered immediately in which case 280 Met. tons/ha (125 tons/acre)	Expected plant uptake of N + 9 Met. tons/ha (4 tons/acre) for OM maintenance + 30% denitrification allowance - 1.2% of organic N in soil
2. Nitrogen and phosphorus application rates	448 kg/ha (400 lbs/acre) total N; 224 kg/ha (200 lbs/acre) total P_2O_5	Expected plant uptake + 15% denitrification - 1.2% of organic N in soil
3. Soil characteristics (permeability)	56 Met. tons/ha (25 tons/acre) if permeability is rapid (16 cm/hr) and no wastes with D.M. <15%. 56 Met. ton/ha (25 ton/acre) if perm. <.5 cm/hr and slope >10%	No manure with D.M. <15% if perm. is rapid (>16 cm/hr) or if slow (<.5 cm/hr) and slope >10%
4. Slope	No manure with D.M. <15% on slopes >10%	No manure with D.M. <15% on slopes >5%. No manure on slopes >20%
5. Distance from surface water capable of leaving farm	No manure <15 m (50 ft) - slope >10%; No manure with <15% D.M. 30 m (100 ft) if slope >5%	No manure <30 m (100 ft) if sodded, <60 m (200 ft) if cultivated. No manure with <15% D.M. 76 m (250 ft) if sodded or 152 m (500 ft) if cultivated

Table 36. (Continued) SUMMARY OF POTENTIAL WASTE DISPOSAL REGULATIONS AT TWO LEVELS.

Parameter	Restriction level 1 [a]	Restriction level 2 [b]
6. Time of year	No manure with <15% D.M. if soil is frozen	No manure between Dec. 7 & April 21 or at any other time if soil is frozen
7. Distance to nearest dwelling or public access	No anaerobic liquid or slurry <152 m (500 ft) from non-farm dwellings. No manure 30 m (100 ft) from dwellings or public access	No anaerobic liquid or solid <302 m (1000 ft) from dwellings. No manure < 152 m (500 ft) from dwellings or access; No irrigation (spray) < 906 m (3000 ft) from dwellings or public access. No storage <302 m (1000 ft) from dwellings or <75 m (250 ft) from public access.
8. Minimum land area	.04 ha/animal unit (0.1 acre/animal)[c]	0.2 ha/animal unit (.5 ac/animal unit)[c]
9. Treatment	secondary - <60 mg/1 B.O.D. <60 mg/1 S.S., <20,000 coliforms/100 ml.	Teritary - <30 mg/1 BOD, <30 mg/1 SS. <100 coliforms/100 ml, <10 mg/1 N, >90% removal of P.
10. Disease control	No spray irrigation if wastes from animals infected with communicable diseases, as determined by a veterinarian, within 302 m (1000 ft) of dwellings or public access	No spray irrigation of wastes from animals infected with communicable diseases as determined by a veterinarian. No pasturing of animals on pasture within 3 months of manure spreading on that land. No pasturing if infected animals within 152 m (500 ft) of surface water.

Table 36. (Continued) SUMMARY OF POTENTIAL WASTE DISPOSAL REGULATIONS AT TWO LEVELS.

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[a] "Intermediate" level.

[b] "High degree" of pollution and disease control.

[c] 454 kg liveweight (1000 lbs)

3 & 4. Physical effects of manure applications are likely to be influenced by the physical nature of the manure. The 15% dry matter division between "liquid" and "solid" manure is set at approximately the limit of pumpability. Liquid wastes are assumed to percolate and runoff more readily than solid manure.

5. In addition to the greater runoff risk expected with liquid wastes, this section allows for differences in the type of crop on which these wastes are spread at restriction level 2. Runoff is likely to be less in quantity and of better quality from sodded slopes than from cultivated, so that different distance limits from surface waters have been provided.

6. It is assumed that liquid manure is likely to have a higher runoff potential from frozen soils than solid manure. At restriction level 2 it is intended that no manure will be spread when there is a 1 in 12 probability of frozen ground.

7. This section recognizes that liquid manure is often anaerobically stored, and consequently highly odorous. At restriction level 2, it also considers the aerosol drift from irrigated wastes, and the risk of pathogen transmittal by this route.

8. The requirement for a minimum land area is designed to provide adequate isolation, and some land area for manure disposal at two levels.

9. The discharge characteristics have been included in this set of control measures so that recognition could be made of the desire of some operators to treat and discharge their wastes. The limits chosen represent a high level of treatment even at restriction level 1.

10. This restriction is intended to give recognition to the problem of disease transmission from infected animals to humans or animals.

METHODS

The purpose of the procedures described in this section is to enable estimates to be made of the economic, agronomic and environmental effects of some of the hypothetical legislation and restrictions previously described. Definitions may be found in the Glossary. The model is made up of two distinct steps as described in Figures 44 and 47.

Step I

The first step is one in which a computer program is used to analyze data given for a dairy farm. The program calculates values associated with a large number of alternative agronomic activities, and stores them for use in Step II (see Figure 44). It can be seen from Figure 44 that the program treats each soil area as a separate entity. Every year of every crop in each rotation, which can be grown on a particular soil area, is treated separately. When the application (or not) of manure at any time of the year is included, this unique cropping situation becomes a "land use activity."

Step I is made up of three sections which can be distinguished as follows:

Nutrient Analysis -

Referring to Figure 45, it can be seen that nutrient inputs to the model are as rainfall, fertilizer and feed. Losses occur as volatilized ammonia, denitrification, leaching, runoff, soil erosion and the sale of crops and animal products off the farm. The manure and fertilizer application rates control the rate of nutrient return to the soil, and consequently influence the rate of loss from the field.

Economic Analysis -

This section analyses the inputs of labor, feed, fertilizers, and other inputs into the activities which grow crops and raise animals (see Figure 46). A careful accounting procedure is used to record the input and production costs associated with every "land use activity," and keep track of the production of feed from each of these activities for use as input for the livestock activities. Only surplus crops are sold off the farm, unless it is more economical to buy feed and sell the crops which have been grown.

Environmental Parameters -

This section consists of a number of sub-models. These sub-models estimate the expected runoff and soil losses from each cropping activity on each soil area. They utilize information generated by sections above, to predict the losses of nutrients in the runoff and eroded soil. The expected loss of nitrogen by

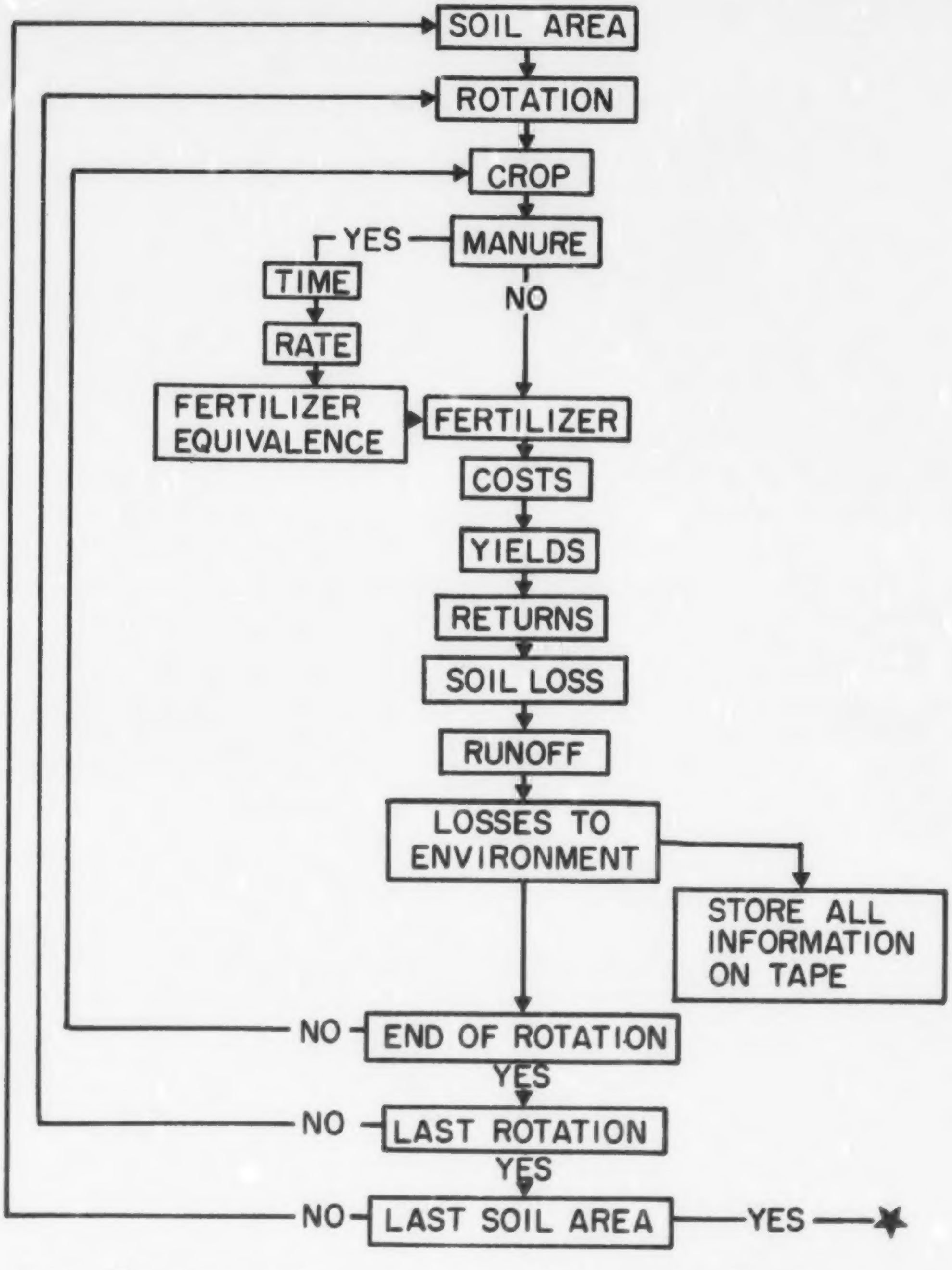
SOIL AREA
ROTATION
CROP
MANURE
YES
NO
TIME
RATE
FERTILIZER EQUIVALENCE
FERTILIZER
COSTS
YIELDS
RETURNS
SOIL LOSS
RUNOFF
LOSSES TO ENVIRONMENT
STORE ALL INFORMATION ON TAPE
NO
END OF ROTATION
YES
NO
LAST ROTATION
YES
NO
LAST SOIL AREA
YES

Figure 44. Schematic representation of the model - Step I.

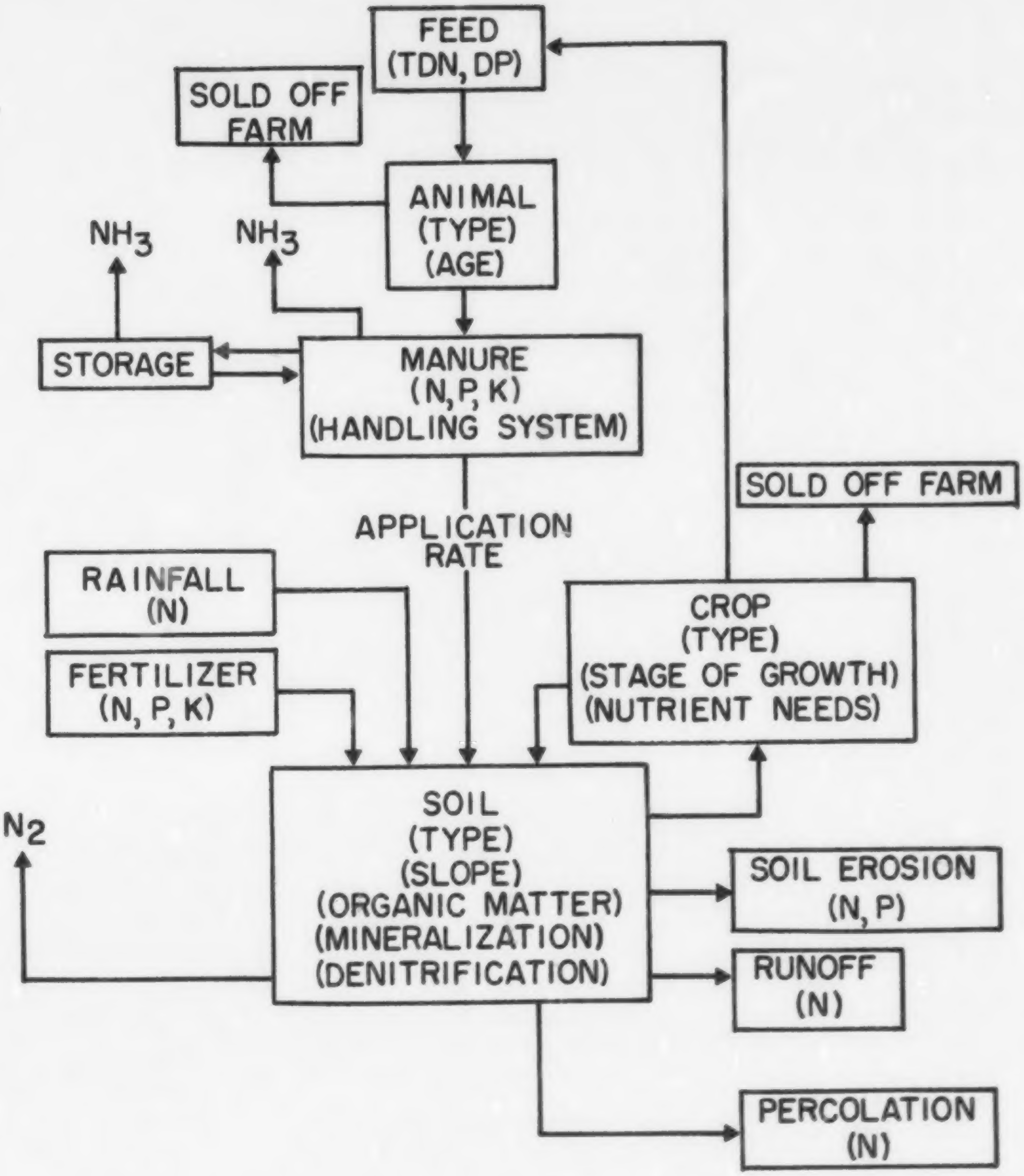
FEED
(TDN, DP)
SOLD OFF FARM
ANIMAL
(TYPE)
(AGE)
NH_3
NH_3
STORAGE
MANURE
(N, P, K)
(HANDLING SYSTEM)
SOLD OFF FARM
APPLICATION RATE
RAINFALL
(N)
FERTILIZER
(N, P, K)
CROP
(TYPE)
(STAGE OF GROWTH)
(NUTRIENT NEEDS)
N_2
SOIL
(TYPE)
(SLOPE)
(ORGANIC MATTER)
(MINERALIZATION)
(DENITRIFICATION)
SOIL EROSION
(N, P)
RUNOFF
(N)
PERCOLATION
(N)

Figure 45. Step I, Schematic representation of the functional relationships of the model - nutrient analysis.

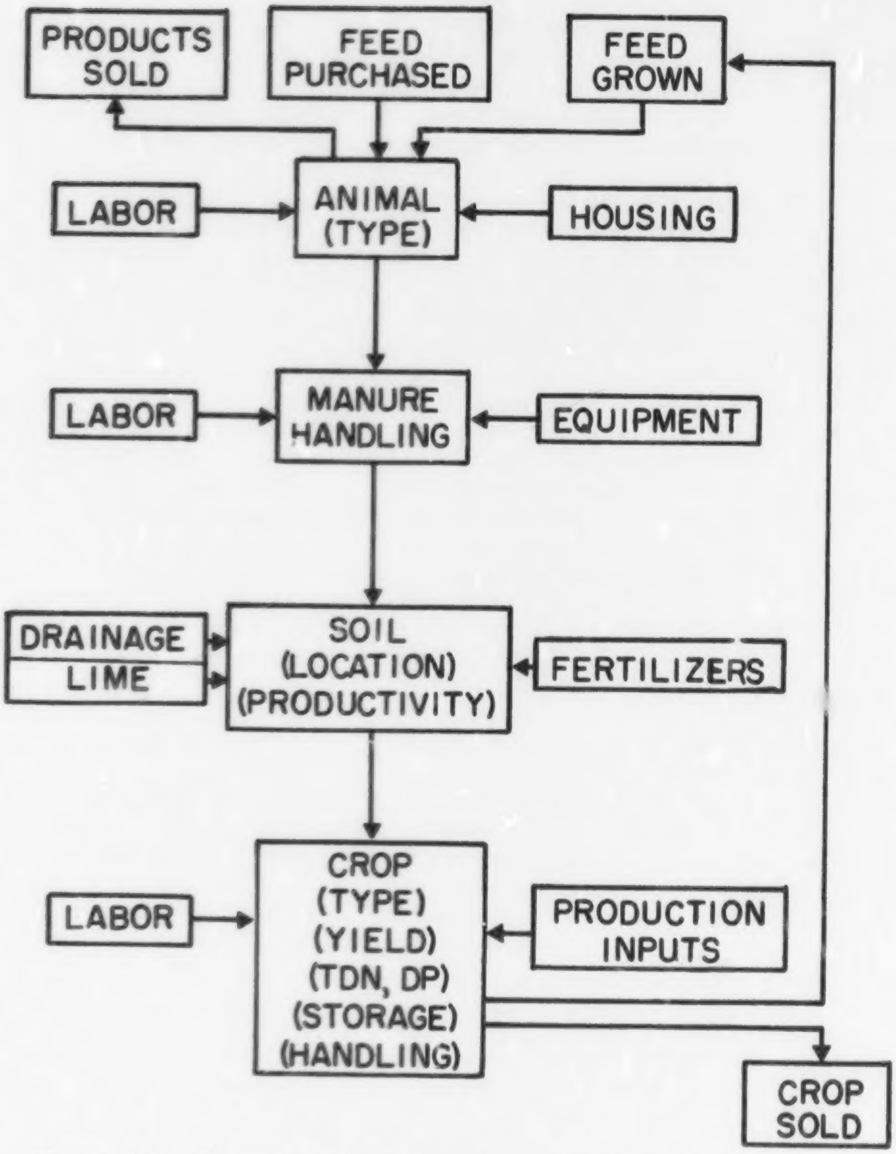
PRODUCTS SOLD
FEED PURCHASED
FEED GROWN
LABOR
ANIMAL (TYPE)
HOUSING
LABOR
MANURE HANDLING
EQUIPMENT
DRAINAGE
LIME
SOIL (LOCATION) (PRODUCTIVITY)
FERTILIZERS
LABOR
CROP (TYPE) (YIELD) (TDN, DP) (STORAGE) (HANDLING)
PRODUCTION INPUTS
CROP SOLD

Figure 46. Step I, Schematic representation of the functional relationships of the model - economic analysis.

percolation and by denitrification is found by the difference between the expected inputs and outputs of N from each soil area under each cropping activity.

Step II

In Step II (see Figure 47), the accumulated information on the alternative land use activities for the farm is incorporated with input data on the non-agronomic (non-land using) activities such as the dairy operation and the buying and selling of feed and crops.

The resulting data is passed through a linear programming procedure which selects that combination of all of the activities which gives the maximum income to the farmer. At the same time, this selection must not violate any of the restrictions which are imposed upon the farm operation by selected portions of the hypothetical legislation previously described. During this selection procedure which is accomplished by linear programming, the land area of the farm is held constant, and the number of cows in the dairy herd is ranged from zero to 150. A complete set of solution values are obtained at each increment in herd size, so that a range of solution may be plotted for each set of hypothetical restrictions. The solutions are plotted and discussed.

A computer program has been written in FORTRAN V to handle Step I of the model. This conducts the nutrient and economic analyses, computes the values of the environmental parameters, and prepares the data for input to Step II, the linear programming optimization procedure.

VALIDATION OF THE MODEL

In the context of the model used in this study, one of the principal reasons for modeling is that the only alternative, conducting field experiments, is almost totally infeasible. Field experiments to collect comparative data of the type used in this study would be extremely expensive and would take many years to complete. Furthermore, it may be impossible to obtain identical field situations large enough for this type of study to be conducted with any degree of experimental accuracy. This is not to imply that modeling is a substitute for real data. Rather, it is an extension of the experimenter's capabilities to infer conclusions from that data which he already has, and point out what types of data should be collected in future research.

If experimental data could be obtained readily and inexpensively, modeling might not always be desirable. The advantages of conducting

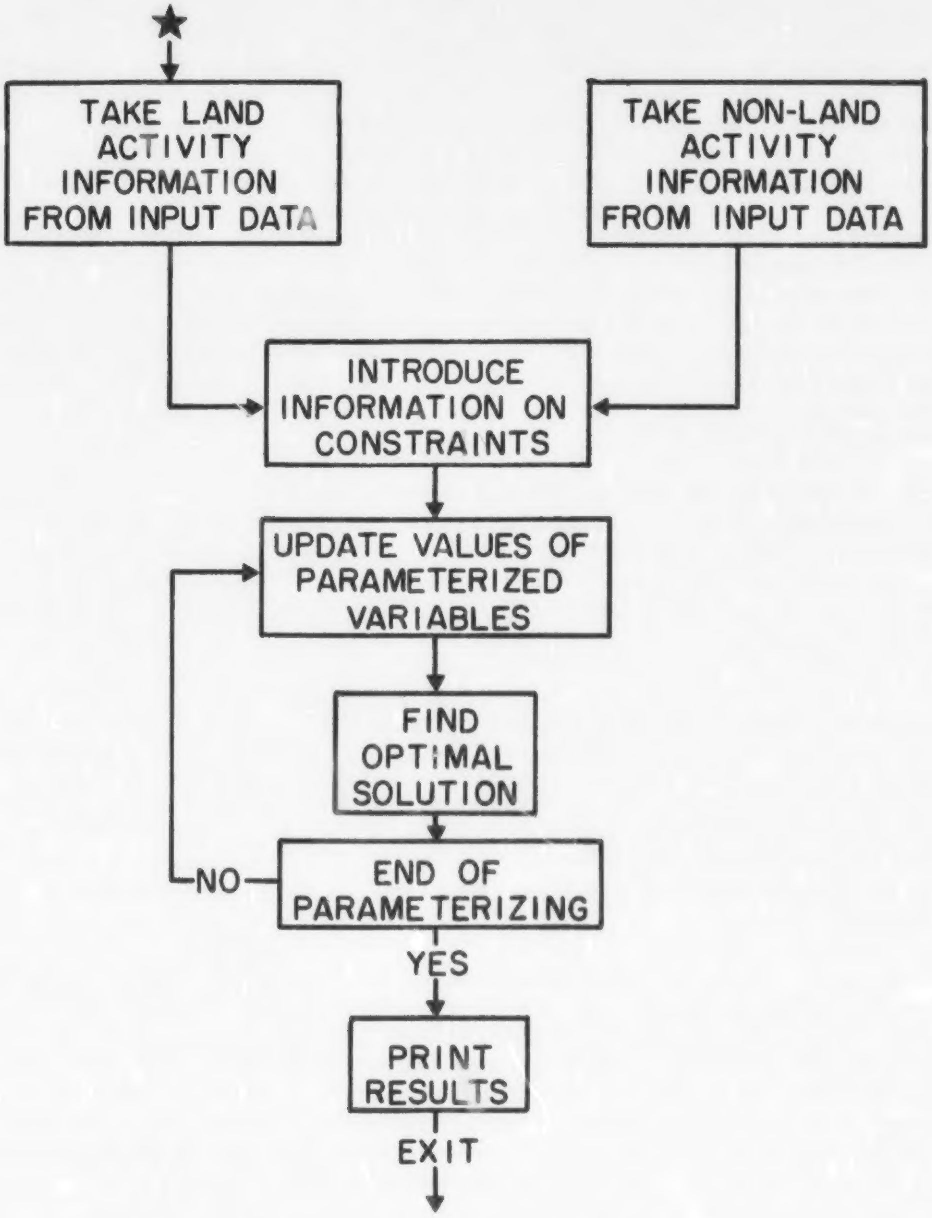
★
TAKE LAND ACTIVITY INFORMATION FROM INPUT DATA
TAKE NON-LAND ACTIVITY INFORMATION FROM INPUT DATA
INTRODUCE INFORMATION ON CONSTRAINTS
UPDATE VALUES OF PARAMETERIZED VARIABLES
FIND OPTIMAL SOLUTION
END OF PARAMETERIZING
NO
YES
PRINT RESULTS
EXIT

Figure 47. Schematic representation of the model - Step II.

experiments to make this type of study are that the data which is measured and collected cannot be disputed, and all variances can usually be accounted for on the basis of observed field conditions. With a model, however, it is unlikely that any set of data can be used without the validity of portions of that data being questioned.

This model is made up of two distinct types of procedures - those which are essentially accounting procedures utilizing data which has been measured and is available, and those which predict the values of certain parameters under a number of different physical conditions. The nutrient analysis, and the analysis of the economic factors involved in the model, are procedures of the first type. Data are available from which representative values may be chosen, and, while it is recognized that some of this data may be questionable under certain conditions, it is usually possible to trace and identify the source of the data, and the conditions which prevailed at the time the data were collected. With this part of the model, validation is not necessary.

With the prediction portion of the model, however, it is necessary to demonstrate that the values which are predicted are reasonable estimates of what might be expected to occur under any particular set of field conditions. The purpose of this section, then, is to present a comparison between values predicted by the model and actual measured values, as far as this is possible with the limited amount of experimental data which is available.

Data are presented on the following pages which allow a comparison of the values of runoff, soil loss, runoff nitrogen, sediment nitrogen and phosphorus, and expected sum of percolation and denitrification nitrogen losses which are predicted by the model, with those which have been measured in the field. The physically measured data were taken from the research findings during 1971 at the Aurora Research Farm. Results were from the runoff study in which mineral fertilizers were used.

The available data is for corn grown on a Lima-Kendaia soil association, with fertilizers applied at two levels, and with free-stall dairy manure spread at 35 t/ha (15 tons/ac), 100 t/ha (45 tons/ac), and 200 t/ha (90 tons/ac). Data is available for wheat at two fertilizer application levels only. The data for corn was obtained at two "management levels," roughly corresponding to the removal or retention of crop residues. These two conditions were considered as approximating corn grown for silage and for grain respectively.

Runoff

Figure 48 shows the relationship between the predicted runoff

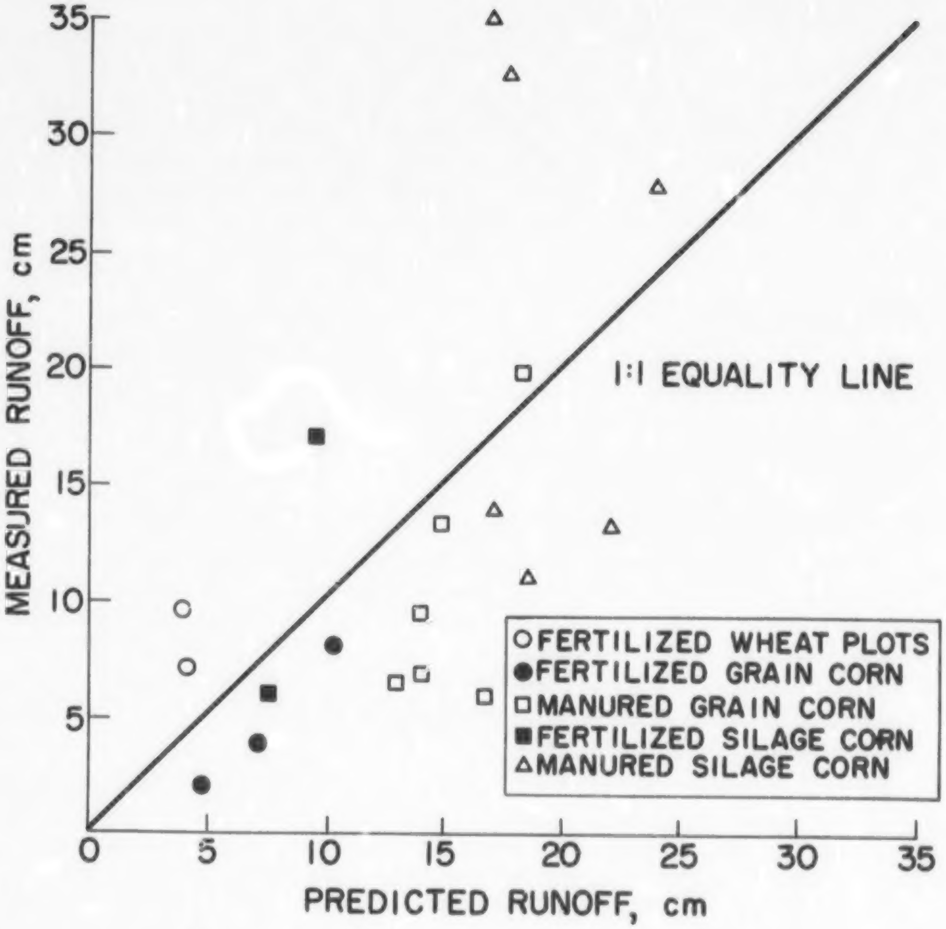

Figure 48. Comparison between predicted and measured runoff, 1971-72.

quantities and the measured values during 1971 and 1972 on the Water Quality Plots at the Aurora Research Farm. The actual measured runoff per acre are shown on the vertical axis, and the predicted values are given in the same units along the horizontal axis. Predicted values were determined by regression, using actual values to develop the equations. The 45° diagonal line represents a perfect 1:1 correlation.

The predicted data points were obtained by modeling both the Lima and the Kendaia soils, and weighting the average of these according to the actual distribution of the two soils in each field plot.

Although there is a considerable scatter about the diagonal equality line, the general relationship between the actual and the predicted runoff is good. This is especially true if consideration is given to the fact that the model assumes far more uniformity in the plots than is found in the field, as can be seen from the figure. The Water Quality Plots are heterogeneous in many characteristics (see for example, Swader (69), Jones and Zwerman (40).

Runoff Nitrogen Losses

Figure 49 shows the relationship between the predicted and the observed quantities of nitrogen loss in runoff water from the Water Quality Plots during 1971 and 1972. All of the remarks made above relative to the runoff volumes apply also to this figure.

Seepage Plus Denitrification Losses

Figure 50 compares the predicted sum of percolation (seepage) and denitrification nitrogen loss with the actual seepage nitrogen loss for 1971 and 1972 at the Aurora Research Farm. The measured values are from tile drain effluent quality samples. They have been used to estimate the total seepage loss of nitrogen by adjusting the seepage volume to compensate for the variations between plots in the actual area drained by the drain tile lines.

It can be seen from Figure 50 that up to about 140 kg/ha (125 lbs/ac) of seepage nitrogen loss the comparison is fairly close. Beyond this amount, however, the actual loss remains fairly constant while the predicted seepage plus denitrification loss continues to increase. The explanation for this would appear to be that the difference between the two sets of figures is made up of denitrification which is not measured. Data presented by Pratt (59), comparing applied nitrogen with the concentration of nitrogen in the soil, shows a very similar trend to that seen in Figure 50.

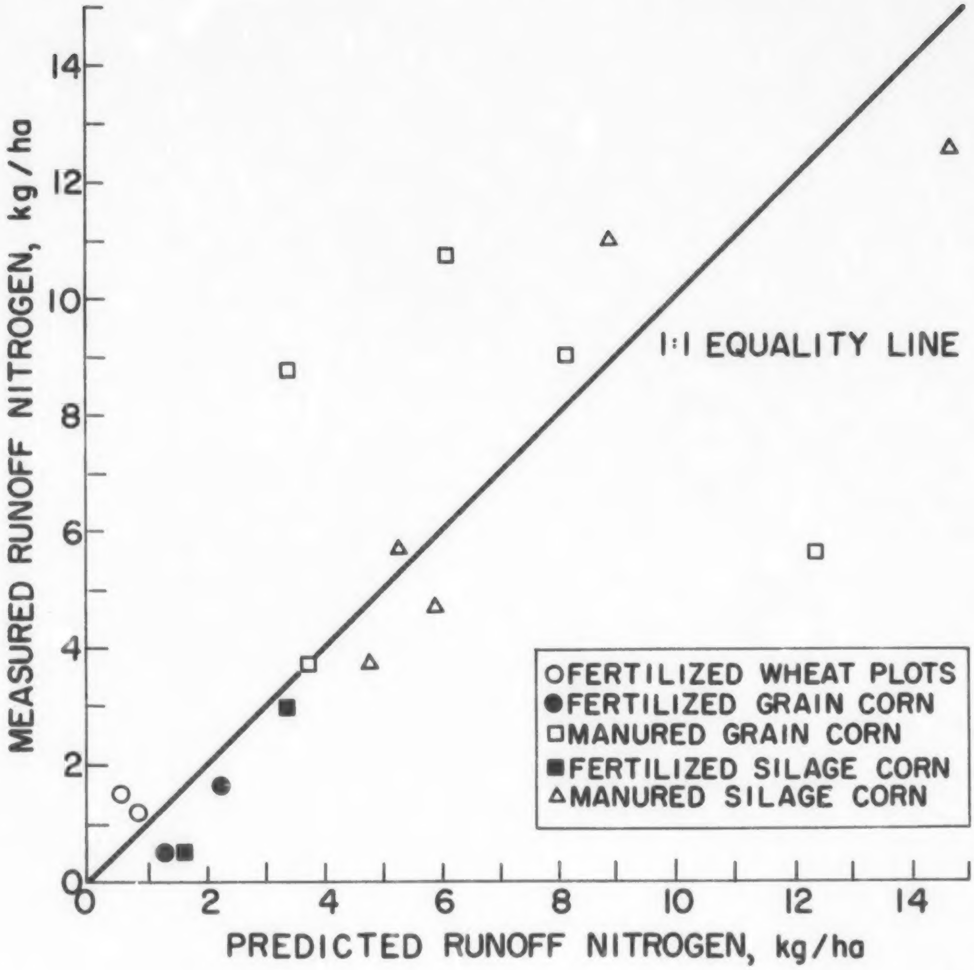

Figure 49. Comparison between predicted and actual runoff inorganic nitrogen loss, 1971-72.

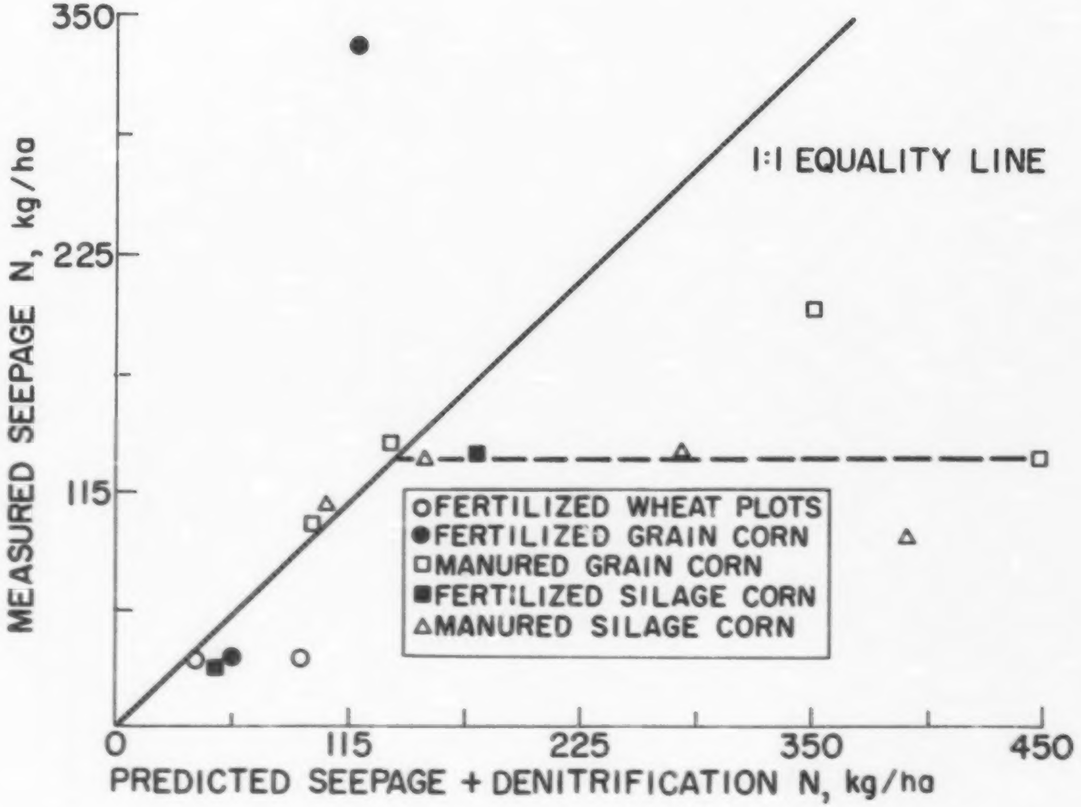

Figure 50. Comparison between predicted sum of seepage and denitrification nitrogen loss and estimated actual seepage loss, 1971-72.

Soil and Sediment Losses

The sediment data has been presented in Figure 51. It has only been possible to obtain sediment data for 1972, which was a year in which there was a very high soil loss due to torrential rains in June. The factors which have been included in the Wischmeier model for soil loss (77), do not allow for small variations in soils and slopes or for wide deviations from average weather conditions. Consequently, the variability in observed values is greater than that in the predicted values of soil loss and sediment nitrogen and phosphorus losses. In 1972 there was only one crop grown, corn, which further limits the ability of the data to check the model. For these reasons, the predicted and observed values have been averaged and presented in histogram form.

The average values for the two crops, corn grain and corn silage are fairly close to the observed values in the field. It would appear that the difference between the two crop conditions is being underestimated by the model. Without a larger range of crops to compare soil losses between the model and the field situation, it is difficult to make more conclusive statements. However, the Wischmeier model has been widely tested and accepted throughout the Northeast for a number of years (see, for example, (17, 22). More than 8,000 plot-years of data went into the development of the model (76). However, potential misinterpretation of the predicted soil loss values should not be overlooked (17), particularly with regard to the distance which this soil is expected to move.

APPLICATION OF THE MODEL

Step I

Manure -

The manure activities are based on the assumption that manure will either be utilized as part of the farm nutrient management plan, or it will be disposed of by dumping on to deliberately unused land. If the former alternative is chosen, it is assumed that the principal restrictions on application rates and time of application will be related to the crop which is being grown. If the latter alternative applies, limits on the maximum "dumping" rate will be imposed by the hypothetical controls of the legislation level used for any solution.

The nutrient release from the manure can only be estimated. It is assumed that the inorganic fraction of the manure nitrogen is immediately available for nitrification, crop uptake or loss to the environment. The organic nitrogen must be mineralized before loss

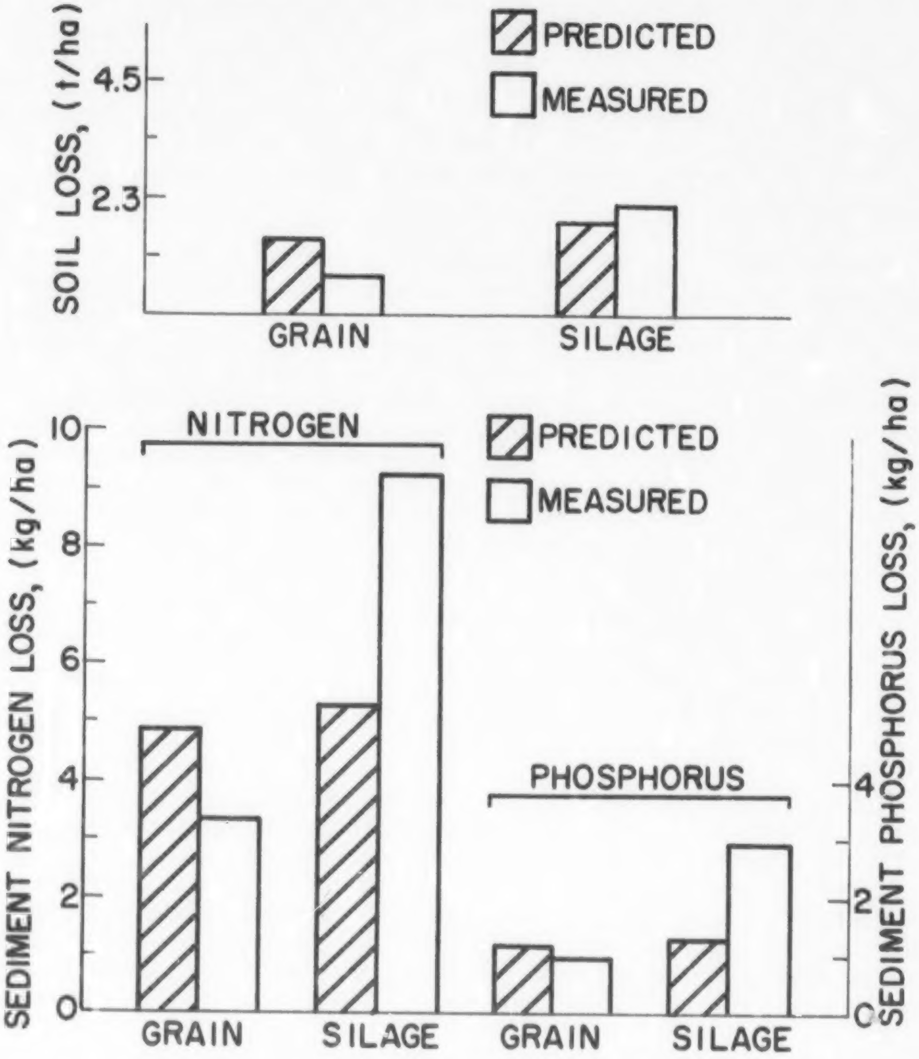

Figure 51. Soil loss, and sediment total nitrogen and phosphorus loss comparisons - predicted (A) vs measured (B) losses.

or uptake can occur. The mineralization is assumed to occur only during those months of the year when temperatures are high enough for crop growth. Because unmineralized manure organic matter will remain in the soil until the following year, the mineralization rate has been estimated for a period long enough for stability of the organic matter to occur. This figure has been used as an annual mineralization rate on the assumption that the system is in equilibrium, and that manure unmineralized in the year of application is balanced by the unmineralized manure which remains from the previous application.

Ammonia volatilized from storage is assumed to be replaced by fertilizer nitrogen, so that a cost was added to the storage costs to reflect the cost of replacing this nitrogen. Ammonia volatilized from storage was included in the total potential nitrogen loss by using the original (before storage) nitrogen content for the calculation of potential nitrogen loss.

In the calculation of manure application rates at Restriction Level 2, the volatilized ammonia is excluded by using the manure nitrogen content after ammonia volatilization. The model does, however, assume that a portion of the winter stored manure ammonia nitrogen loss is available for crops if spread in the summer or fall. Therefore the calculated application rates at these time periods are slightly lower than would, in reality, be allowed under the terms of Restriction Level 2 (see Table 37), for manure which has been stored.

Time Periods -

Although the model is capable of accepting almost any number of time periods, it was decided that these would be limited to four, corresponding approximately with the four agricultural seasons. A greater number of time periods greatly increase the time taken for the model to be run through the computer. Simplifications were made in the time periods in the equations of the model where changes were unlikely to occur between time periods. For example, it was assumed that the same number of animals were kept during each time period so that some equations involving animal numbers were simplified to an annual basis for computational purposes. Equations which deal with the feed requirements of the animals were simplified in this way. Similarly, the fertilizer and nutrient loss data were calculated in the program on an annual basis rather than by time periods, to avoid the problem of manure and nutrient retention in the soil from one time period to the next. Equations were simplified in this manner for computational purposes.

Table 37. RESTRICTIONS USED FOR CONTROLLING MANURE DISPOSAL ACTIVITIES ON TWO HYPOTHETICAL NEW YORK DAIRY FARMS (SOLID MANURE ONLY). [a]

Parameter	No restriction	Restriction level 1	Restriction level 2
1. Application rates of manure	450 t/ha (200 tons/ac)	112 t/ha (50 tons/ac)	Expected plant uptake of N + 9 t/ha (4 tons/acre) for organic matter maintenance + 30% denitrification allowance - 1.2% of organic N in the soil (mineralization)
2. Nitrogen and phosphorus application rates	none	448 kg/ha (400 lb/acre) total N 224 kg/ha (200 lb/acre) total P_2O_5	Expected plant uptake of N + 15% denitrification allowance - 1.2% of organic N in the soil (mineralization)
3. Soil characteristics (permeability)	none	56 Met. tons/ha (25 tons/acre) if permeability rapid (16 cm/hr) 56 Met. tons/ha (25 tons/acre) if permeability <0.5 cm/hr and slope >10%[b]	None applicable
4. Slope	none	none applicable	No manure on slopes >20%[b]
5. Distance from surface water capable of leaving farm	none	none applicable	No manure <30m (100 ft) if sodded or 60 m <(200 ft) if cultivated

Table 37 (Continued). RESTRICTIONS USED FOR CONTROLLING MANURE DISPOSAL ACTIVITIES ON TWO HYPOTHETICAL NEW YORK DAIRY FARMS (SOLID MANURE ONLY).[a]

Parameter	No restriction	Restriction level 1	Restriction level 2
6. Time of year	none	none applicable	No manure during "winter" time period (Dec.-April)
7. Distance to dwelling or public access	none	No manure <30m (100 ft) from	No manure <151 m (500 ft) from dwellings or public access. No storage <151 m (500 ft) from dwellings or <75 m (250 ft) from public access.
8. Minimum land area	none	0.04 ha/animal unit (0.1 acre/animal unit)	0.2 ha/animal unit (0.5 acre/animal unit)[c]
9. Treatment	none	none applicable	none applicable
10. Disease control	none	none applicable	none applicable

[a] Essentially same as Table 36, with controls applicable to liquid manure excluded.

[b] No soil conditions present on the farms used in this study to which this control would apply.

[c] 454 kg (1000 lbs) liveweight

Management Levels -

In this model, only one management competence level is assumed. This simplification is intended to avoid the problem of generating large numbers of alternative land use activities, each at a different management level. The level of management chosen is approximately that of the average farmer in the Cost Account Program of the Department of Agricultural Economics at Cornell University. This asssumption simplifies the problems of selecting data consistent with any given management level.

Crop Rotations -

The number of crop rotations for any one farm is restricted to six, with a maximum of three of these for any one soil type.

Crop Yields -

It is assumed that for a given crop there are three yield levels. A yield goal can be achieved on a given soil type with the correct fertility level. Not all yield levels are attainable on all soil types. The combination of fertility level and yield goal for a particular soil is a judgment which must be made in the light of knowledge of the capability of the soil and the expected management competence of the farmer. Figure 52 shows the relationship of yields and fertility levels to soil capability. The numbers in the matrix indicate soil capability from poor (1) to high (5).

yield level ↓	Fertility → 1.	2.	3.
3.	3	2	3
2.	4	3	2
1.	5	4	3

Figure 52. Fertility yield matrix for five soil capability levels.

With additional programming, it would be possible to use production function data for selecting the optimum application rates of fertilizer for each crop on each soil type. However, sufficient data for this to be done with any consistency is difficult to obtain for the locations and all of the soil types used in this model. As data consistency is best obtained by utilizing data from similar sources, the approach above was chosen for yield and fertility expectations utilizing data will be described later.

Fertilizer -

It is assumed that all fertilizer applications are made during the months of May and June.

The nitrogen, phosphorus and potassium requirements of the crops are determined from average actual fertilizer levels with and without manure applications. It is therefore assumed that the contribution of mineralized organic matter, present in the soil before the manure application was made, and rainfall have already been accounted for.

Costs -

Certain costs which have been included in the model as variable costs, such as those associated with crop growing activities, include some costs which are not completely variable. For example, costs per acre associated with cultivation and harvesting machinery have been assumed to be unaffected by the acreage of a particular crop grown. This assumption greatly simplifies the handling of cost data for the large number of alternative crop growing activities and facilitates the use of linear programming for optimization.

Structural costs, such as those associated with the animal housing and milking facilities, have been handled as far as possible as fixed costs, at each herd size.

Labor -

To simplify the labor distribution between the unpaid labor supplied by the farmer and his family, and that supplied by the hired help, it is assumed that the cost of labor in the individual computation equations is zero, but that hired labor has to be paid for. Thus the optimal solution is one which utilized all of the unpaid labor, for any particular time period, before any hired labor is introduced into the system.

Soil Distribution -

To enable each soil type to have an equal probability of occurring anywhere on the farm in relation to such physical features as the barn, roads, streams etc., a circular design was chosen for the farm. Each soil area (separated by soil type and slope) is arranged as a segment of the circular farm area (see Figure 53). The barn is assumed to be located at the center, and since most farms are bordered, at least in part, by a public road, it was decided to locate a road around the circumference of the circle. A stream was arbitrarily located midway between the barn and the road. It should be noted that the effect of this design is to have a stream passing through all soil types, whereas in reality this will not always be the case. However, it is also possible, in reality, that a soil type which would not ordinarily have a stream passing through it may be in close proximity to a stream, as there is often an abrupt change in soil type within a short distance as creeks are approached. Thus, while the assumption used may not always be correct, it also may be a close approximation to reality in many instances. Since the circular design of the farm minimizes the distance of any point from the barn, transportation distances for manure spreading are increased by a factor of 39%, the relationship between the two sides and the hypotenuse of an isosoles triangle, to reflect the actual road distances involved in traveling between points on the farm.

Woodland -

No deliberate attempt is made to exclude a portion of the farm for woodland, although it is recognized that the average farm in New York has approximately 20% of its soils in woodland. It is assumed that the optimum solution to the management problem will take into account the same type of factors which lead a farmer to leave a certain acreage in woodland rather than cultivate or grow pasture on the entire farm. Land left idle by the modeling procedure is assumed to return to woodland. It has been assumed that the amount of land in hedgerows is not large for any one soil type, and this potentially unused land is assumed to be included in the land left idle by the model.

Purchased Feed -

It was originally anticipated that the model should permit the linear programming solution to include any combination of practices which would maximize revenue. The costs and crop yields expected in the one location, as used in the model, are such that when the first set of solutions were obtained, almost all feed was required to be purchased.

This is not likely to represent reality, even though it may be the economically optimum solution for the data used. When the constraints were altered to require that all forage should be grown on the farm, it

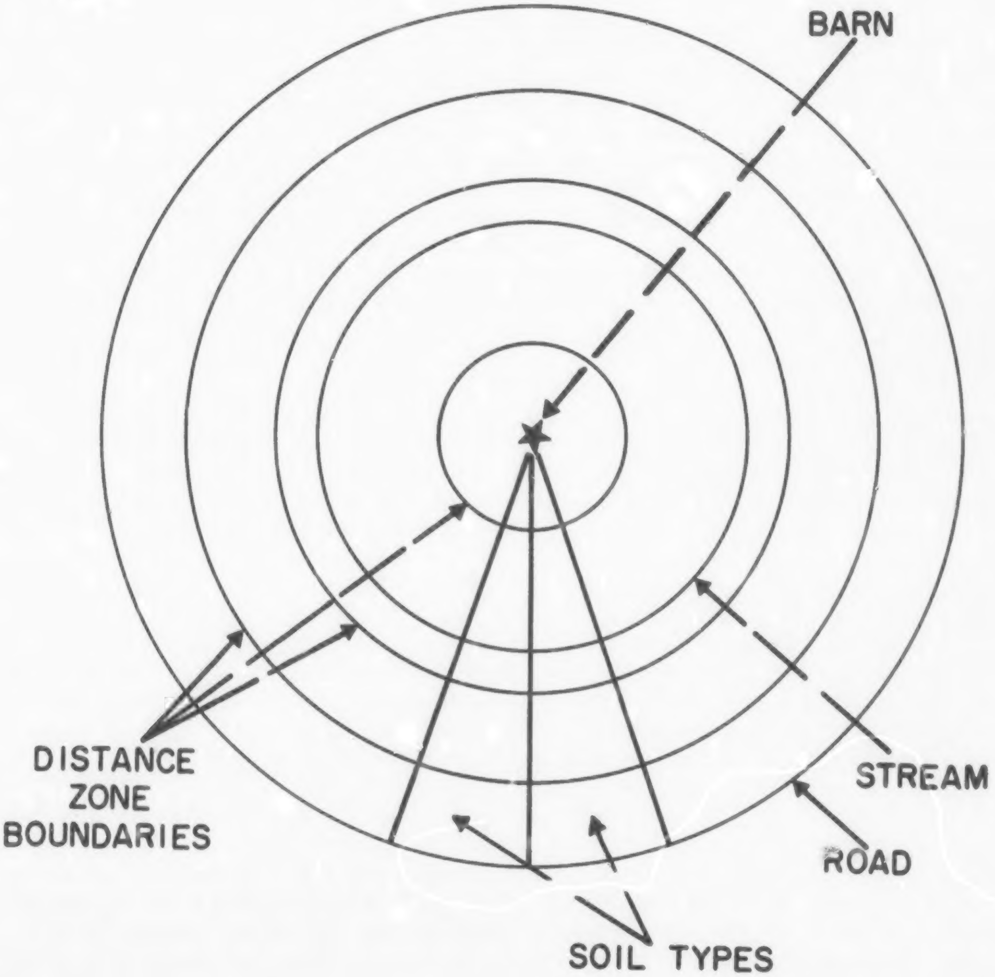
BARN
DISTANCE ZONE BOUNDARIES
STREAM
ROAD
SOIL TYPES

Figure 53. Physical model of the farm. Area of circle represents total area of farm. Soil type zones are distributed around the circle in proportion to their area on the farm.

became impossible to obtain a feasible solution after a herd size of 83 cows was reached. This was partly because of the low yields expected on these soils and partly because of the rotation requirements, which were such that crops which did not supply forage were needed to complete the rotations. Beyond 83 cows there was no solution which would supply the necessary forage from crops grown on the farm under the conditions of the model.

The requirement that all forage should be grown on the farm may be reasonable for farms with low cow/land ratios. However, it was desired that cow/land ratios in the model could be increased to higher values than are usually encountered in the region, for the purpose of comparing environmental parameters. It has been necessary to compromise on the question of forage production, and this is accomplished by allowing the purchase of up to 50% of the necessary forage, if the model so desires. As will be discussed, this limit may have a pronounced effect on the solution parameter values for the model farm.

Capital -

In this model no constraint is placed on capital used in the farm operation. It may be necessary to include such a constraint if the model is expanded to include consideration of treatment plants for manure disposal, or any handling system which is likely to involve large capital commitments.

Legislative Controls -

Legislative controls on the activities of the farmer, relative to manure disposal, are imposed on the modeling procedure during Step I of the model. This means that the data prepared and presented to Step II, the linear programming procedure, is determined, in part, by the hypothetical controls which apply to the particular set of solutions to be obtained.

Imposing the controls before the optimization step is a feature of this model, and it is not intended to imply that this is the only way in which these controls might be imposed. It might be advantageous, for example, to set up the model so that the legislative controls would be imposed on the linear programming procedure. This would enable shadow prices to be computed for each control. The nature of this type of study, however, is such that to do this would either involve utilizing an even larger number of alternative activities, or greater simplification of the manure disposal interactions. It was decided that the approach taken in this model was most appropriate for the type of study intended for this presentation.

The hypothetical controls which were outlined have been used as a guide for the application of controls to the farms used in this study. Table 37 summarizes the controls which are used. Since this study did not include any consideration of liquid manure handling, even though the model was set up to be used with either liquid or solid manure, many of the controls outlined in Table 36 are not included in Table 37.

Step II

There are a number of assumptions which must be accepted when linear programming is used. These include linearity of functions, additivity and divisibility of activities, and the need for a finite number of activities (33). These assumptions are all generally considered acceptable in agricultural problems, except for the assumption of linearity (31). Linearity can be approximated, however, by the acceptance of a number of simplifying assumptions with regard to economies of scale in crop production. In this model, for example, economies of scale in the use of crop growing and harvesting machinery are not considered. Average values for the costs of these items, in crop growing budget analyses for similar New York farms, are used throughout the model. Non-linearity in dairy operations, however, has been recognized and adjustments made to the costs associated with milk production to reflect the economies of scale in housing and dairy facilities.

While Heady and Candler (31) point out that situations involving economies of scale cannot be included in linear programming activities, the assumptions which have been made regarding linearity of crop growing costs and returns do enable these activities to be approximated. Thus it must be borne in mind when considering the solutions obtained by the linear programming procedure that these economies of scale do exist. Were the activities to be re-programmed with coefficients adjusted to reflect the economies of scale of previous solution values, some change in solution values might occur.

The linear programming procedure has been widely used in the past for solving agricultural optimization problems (4, 51, 64). Smith (65) has used linear programming to study optimum allocation of cropping practices for income maximization on a New York dairy farm. Linear programming has been used in this study in a similar way to that in which it has been used by Smith (65).

DATA USED IN THIS STUDY

The data used in this study were chosen to approximate the real situation on New York dairy farms in the regions studied. The purpose of the study was one of comparison between regions and hypothetical controls. The actual computed values of the parameters, presented should not be used by any reader unless he has satisfied himself that the data used are acceptable to him.

Location of Study Farms

It was desirable to have farms which were located in regions of New York State which are densely populated with dairy cows. The regions also had to represent a wide variation in soils and topography. Studies of the distribution of dairy cows in New York and of the Soil Survey reports indicated two regions which satisfy these requirements. The first was the townships of Cape Vincent, Clayton and Lyme of Western Jefferson County, and the second was the townships of Augusta and Vernon of Oneida County. The former location is also of interest because of the possible relationship between agriculture and the pollution occurring in the eastern bays of Lake Ontario and the International section of the St. Lawrnence River (see for example Cliff Carpenter, Ithaca Journal, Nov. 7, 1972.).

In very general terms, the Jefferson County region used in this study is one of poor soils and flat slopes, and the Oneida County location is one with highly productive soils and relatively steeper slopes.

Size of Farms

In each region the size of farm studied was made to conform as closely as possible to the average size of the dairy farms of those townships included in the region. The data for farm sizing was obtained from the 1964 Agricultural Census of Agriculture (9 and 10) and adjusted by the percentage change during the previous five years to approximate the size of farm for 1969.

Soils

Soil data was gathered from the published Soil Surveys of the counties studied. The bulletin on Soils and Soil Associations of New York by Cline (15), pamphlets on the Soils and Soil Associations of Jefferson County and Oneida County (34, 58), Bizzell's (7) bulletin on Chemical Properties of New York Soils and Cline's (14) Physical and Chemical Properties of New York Soils were all used to estimate essential soil data for use in this study. Soils very similar in properties of interest to this study were grouped together to simplify the computations made in the model.

Slopes -

Slopes of soils were approximated as the average slope occurring with each soil type providing that the range did not exceed 5% in slope. Where there was more variation than 5%, the slope was divided into two or more equal sized areas each with an average slope covering the range of slope for that area.

Crops

Crop data was obtained for 1969. Analysis of weather data indicated that of the last three years for which data is available, 1969 had the smallest variation from the 30-year mean for temperature and precipitation (Table 38). Years prior to 1969 were not considered because of the constant changes which are taking place in agricultural technology which makes data from earlier years unreliable.

Crop yield data was estimated from the annual reports of the Cornell University Agricultural Economics Cost Account Program (41). The highest yield level approximately corresponded to the average yields of the top two farmers in the cost account program. Robinson and Hope (60) have shown that the top three farmers in the Cost Account Program have consistently received yields which were comparable to the yields obtained by the Plant Breeding experiments in New York. The intermediate level yields were approximately the same as the average of the Cost Account Program, and the lowest level corresponded to the average of the lowest three farmers in the program.

Table 38. STANDARD DEVIATION FROM 30-YEAR MEAN, 1969-1971, TEMPERATURE AND PRECIPITATION OF WEEKLY AVERAGES FOR GROWING SEASON AT SIX CENTRAL NEW YORK WEATHER STATIONS.[a]

Year	Temperature, °C	Precipitation, cm
1969	16	1.31
1970	15	1.86
1971	15	1.50

[a] Data compiled from USDA Stat. Rep. Ser. and from data supplied by B. Pack, Cornell Univ.

Rotations

Some of the rotations were selected from the rotations which were studied by Prof. Robert Musgrave at Cornell University in his long term rotation study at the Aurora Research Farm (52). Others were chosen as being representative of the rotations used in the regions in which the farms being studied were located. In order that the model would function correctly, it was necessary to approximate the concept of "continuous" corn by using a rotation of five years of corn followed by two years of alfalfa. The model is not capable in its present form of handling an "open ended" rotation such as continuous corn, since the number of years that the crop is grown in the rotation determines the fertilizer rate.

Fertility

Wherever possible, average fertilizer applications obtained for each crop from the data of Kearl and Snyder (41, 42) were used as the intermediate fertilizer application needed to obtain average yields on a soil of intermediate production capability. These fertilizer levels, with adjustments for manure applications, were arbitrarily increased by 50% and decreased by 50% to obtain the high and the low fertility levels respectively. These levels were then used, with the available data on the productive capacity of each soil, to fit the soil, yield and fertility level into the matrix of Figure 52 in such a way as to best approximate the management level of the average Cost Account Program farmer.

Published data conflict on the question of the possibility of maintaining yields of corn in continuous culture even with annual increments of nitrogen fertilizer. Barber (3) shows that there is a decline of approximately 3% per year in corn yields during the first five years of continuous cropping with equal nitrogen fertilizer applications each year. Schrader *et al*. (63), however, show that when organic residue nitrogen is included in nitrogen applications, the yields obtained in all years fall on a common nitrogen response curve. This difference was resolved in this model by allowing a 2% decline in yield with a 10% annual increase in nitrogen applications, where no manure was applied. If manure was applied, no decline in yield was assumed. This takes into account the approximate 2% increase in yields of corn observed by McEachron *et al*. (52) which was attributable to the inclusion of manure in the nutrient applications.

Manure

Manure was assumed to be spread on field crops at a maximum rate of 44.8 Met. tons/ha (20 tons/acre) unless the controls for the soil area involved were such that this application rate had to be reduced. Where manure was "dumped", it was assumed that this was done at the maximum rate allowed. Where no restriction applied, the maximum dumping rate was 448 Met. tons/ha (200 tons/acre) which was somewhat higher than the maximum dumping rate observed by the author while visiting representative dairy farms in New York.

Estimating the rate of mineralization of manure nutrients is difficult, as little information exists on this subject. Carbon-14 studies have been conducted by Jenkinson (38) on the decomposition of fresh plant material. Jenkinson's data, and that of Bouldin and Lathwell (8) and that found in the previously discussed experiment dealing with land application, suggest that about 75-85% of manure organic matter can be assumed to be eventually mineralized over a period of several years. In this model it has been assumed that 50% is mineralized during the first year, and another 20% during the second year. The remaining 30% is assumed to represent that part of the organic matter which becomes incorporated into the stable "humus" fraction of the soil. All of the ammonia and inorganic nitrogen in the manure is assumed to be available immediately for crop uptake, leaching, or loss as volatilized ammonia. The proportion which is lost by leaching and volatilization will depend on the time of year that the manure is spread, and has been estimated for each time period according to the expected weather conditions during each time period. Warm day conditions have been assumed to encourage volatilization and cool wet conditions to encourage leaching. Ammonia volatilization during six months of storage has been assumed to be equivalent to the entire ammonia content of the manure when fresh from the barn, as suggested by Weeks (74). Half of this was assumed to occur during three months storage.

Manure is assumed to have a beneficial effect on soil aggregate stability as has been shown by Zwerman et al. (79). They also found a direct relationship between aggregate stability and soil erosion loss, which approximated a 30% reduction in soil loss at manure application rates of six tons per acre. A 30% soil loss reduction has therefore been included in this model for application rates of manure of 13.5 Met. tons/ha (6 tons/acre) or more.

Livestock

Livestock was restricted in this study to dairy cows and replacement heifers. Management was assumed to be at a comparable level to that of the average farmer participating in the Cornell Cost Account Program (41). The most recent data which is available from this program has been used for all factors of production of livestock.

Precipitation

Precipitation data for the runoff prediction sub-model was obtained from the United States Weather Bureau monthly report on the weather of New York State. All Storms of 0.25 cm or more were grouped into three groups: 0.25-1.25 cm, 1.25-2.54 cm and greater than 2.54 cm. The average storm size within each group within the time period being considered was used with the total number of storms during that time period, in that storm group, as a simplification of the precipitation input data for the model. The records of the nearest weather station to the region being studied was used as the source of data. Averages were computed using the last five years of weather records. Storms of less than 0.25 cm were assumed to result in no runoff.

Selective Erosion Indices

It has been observed (6, 79) that the concentration of nutrients in eroded material is usually higher than that in the soil from which the sediment eroded. This has been referred to as an "enrichment ratio". However, this term has been used in this study to describe the increase in nutrients in the soil from a land-use activity. The term "selective erosion index" has therefore been used to describe the phenomenon described above (see Glossary). Data for selective erosion indices for organic matter and phosphorus have been taken from the study of Zwerman and Klausner (79).

RESULTS AND DISCUSSION

The regions, Western Jefferson County and Southwest Oneida County, were chosen because of the large differences between them in soil characteristics. These differences had a considerable effect on the results of the optimizing procedure, as will be described below.

The solutions which are presented represent three conditions. First there is the condition under which there are no restrictions imposed on the solution by legislative action. It is assumed that the farmer will consider only his profit maximization with no regard for the external consequences of his activities. At Restriction Level 1, it is assumed that no activity will violate the requirements of Restriction Level 1 in Table 37. At Restriction Level 2, it is assumed that the requirements of Restriction Level 2 of Table 37 will not be violated.

It should be impressed upon the reader, at this point, that the controls which were applied to the model did not include all of the factors considered in Table 36. The reasons for this is that Table 36 covered a number of situations which this study was unable to include. Further studies which do include these situations, specifically liquid manure handling and storage, and manure treatment, are recommended.

Of the ten factors included in the original table of restrictions (Table 36), only seven were seen to be relevant to the conditions studied here. All of these seven were involved in the controls at Restriction Level 2, which is considered to be representative of a high degree of control over the farmer's decision making. At Restriction Level 1, an intermediate degree of control, only five of the original ten factors were operative.

The average farm size of the Western Jefferson County townships of Lyme, Cape Vincent and Clayton, was found to be 121 ha (306 acres) and that of Augusta and Vernon townships of Southwest Oneida County was found to be 86 ha (212 acres). These farm sizes are used in the model for the appropriate region. The herd size of dairy cows in the model is ranged from 10 to 150 cows in 20 cow increments. The wastes from the replacement heifers are included in the waste disposal of any given herd size, so that the actual herd size generating the wastes is approximately 25% greater than indicated on the curve. However, since it is common for some replacements to be raised on a New York dairy farm, it is not unreasonable to include this manure with that of the dairy cows at any given herd size.

Net Revenue

Figures 54 and 55 represent estimates of the net revenue from each farm. In the Jefferson County region, it can be seen that up to a herd size of approximately 30 cows, there is little difference between the net revenue regardless of the level of restriction which is imposed. Beyond 30 cows, or 0.25 cows/ha, (0.1 cows per acre) the restrictions imposed at level 2 force the farmer to grow more crop acreage than he would otherwise do, and, since on these particular soils it appears to be not profitable to grow crops for sale off the farm, the farmer's net revenue falls. At 35 cows or 0.32 cows/ha (0.13 cow/acre), the restrictions force the solution into an infeasible state as it becomes impossible to dispose of the manure without violating the restrictions, and the process of increasing herd size stops. At "No Restriction," and Restriction Level 1, there is a slight drop in "net revenue" between 50 and 90 cows which would appear to be caused by the slightly higher costs associated with the use of a milking parlor which is used at all herd sizes greater than 50 cows. Beyond a herd size of 90 cows, there is an almost linear increase in net revenue. If the herd size was to be increased beyond 150 cows, net revenue could be expected to continue to increase until the solution became infeasible due to shortage of manure disposal land, with a probable reduction in net revenue at a herd size greater than 150 cows before the infeasible point is reached.

There is apparently no effect on net revenue from the imposition of Restriction Level 1 on the Jefferson County farm, up to the maximum herd density of 1.24 cows/ha or 150 cows (0.5 cows/ac).

When the herd size on the Oneida County farm is increased to 150 cows a slight reduction in net revenue occurs under Restriction Level 1. This occurs, however, at a higher density of cows per acre than is reached in Jefferson County, because of the smaller farm size, 86 ha (212 acres) as compared to 121 ha (306 acres) in Jefferson County.

When Restriction Level 2 is applied to Oneida County there is not the noticeable drop in revenue before infeasibility occurs as is seen in Jefferson County. The reason for this is because the soils on the Oneida County farm appear to be such that it is possible to grow and sell crops at a profit. Thus the effect of the regulations is simply to prevent the herd size from being increased because of shortage of manure spreading land. On the Jefferson County farm the same regulations force unprofitable crop rotations to be used in order to have a place for manure disposal, and so a rapid drop in net revenue is observed before infeasibility is encountered.

The effect of the soils on net revenue is clearly demonstrated at the zero cow level, where there is no revenue at all from the Jefferson County farm, but the Oneida County farm yields a reasonable net revenue from the sale off the farm of crops which can be produced at a profit.

Referring to Figure 55, it can be seen that where there are no cows, Restriction Level 2 actually increases net revenue compared to the situation where no restriction applies. The explanation for this is that Restriction Level 2 forces the fertilizer application rate to a level which is not much higher than the uptake of nutrients by the crop. The saving in the cost of fertilizers is reflected in the increased net revenue from the farm operation.

Manure Unutilized or "Dumped"

Figures 56 and 57 show the effect of the restrictions on the amount of manure which is disposed of by dumping onto unused land. Restriction Level 2 prohibits all dumping, so that all values of dumped manure are zero. At the Jefferson County location, there is no increase in the amount of manure dumped per cow, as the herd size increases, at Restriction Level 1 and when there is no re-

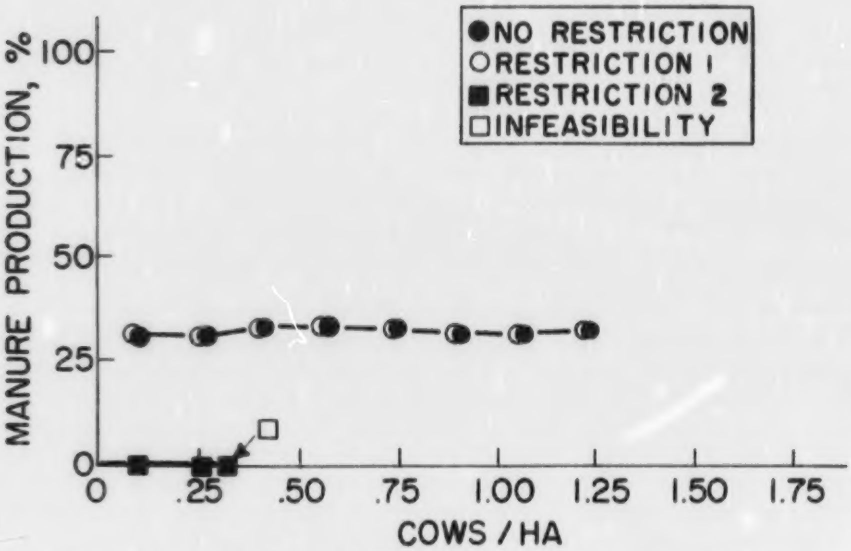

Figure 56. Amount of manure "dumped" - W. Jefferson County.

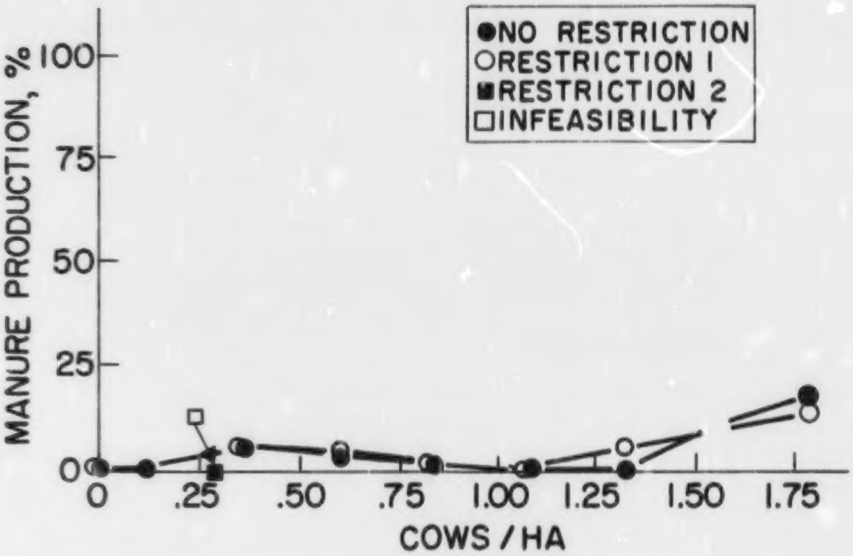

Figure 57. Amount of manure "dumped" - S. W. Oneida County.

striction. The amount is approximately 30% of the total manure production (also shown in the figures). Had the model required more than 50% of the forage requirement of the herd to be home-grown, it is likely that even less manure would have been dumped as there would have been more crop acreage on which to utilize the manure.

On the Oneida County farm, there is very little dumping of manure until a 100 cow, or 1.24 cows/ha (0.5 cows per acre) herd size is reached. The large acreage of crops has a large requirement for nutrients and the manure is used to supply as much of this requirement as possible. Restriction Level 1 causes the dumping process to start at a slightly lower herd size than when no restriction applies, due to the effects of this restriction on reducing the amount of cropped land on which manure may be spread.

It is of interest to note that at no time did the optimum combination of activities, as selected by the linear programming procedure, require the dumping of all the manure produced. Since any bias in favor of manure spreading in this model has been deliberately avoided, it must be concluded that the concept, sometimes advocated, of maximum profits being obtained only when all crop nutrient requirements are met with fertilizers, and where all manure is dumped, is probably quite false for New York conditions.

Crops

Figures 58 through 63 show the effect of the regulations on the cropping practices on the two farms. Again, it can be seen that at the Jefferson County location, there was no difference between Restriction Level 1 and "No Restriction." Alfalfa, corn and oats are interdependent because of the dominance of the corn-oats-alfalfa-alfalfa rotation in the model for this farm. At Restriction Level 2, in Jefferson County, the relationship between these three crops changes. This is found to be the result of a change in the rotations under this restriction level. A corn-oats-grass-grass-grass rotation was introduced because, though less profitable than the other rotations, it made available an area of land for manure spreading which the others did not. The grass in this model was considered a suitable crop to be spread with manure, while the alfalfa was not - consistent with popular assumptions.

In the Oneida County location, more rotations were included in the solutions. The most profitable rotation in this area is the model's nearest approximation to continuous corn - five years of corn and two years of alfalfa. However, this rotation is too restrictive in terms of seasonal availability of land for manure spreading, particularly in the summer, so that as the herd size increases a rotation

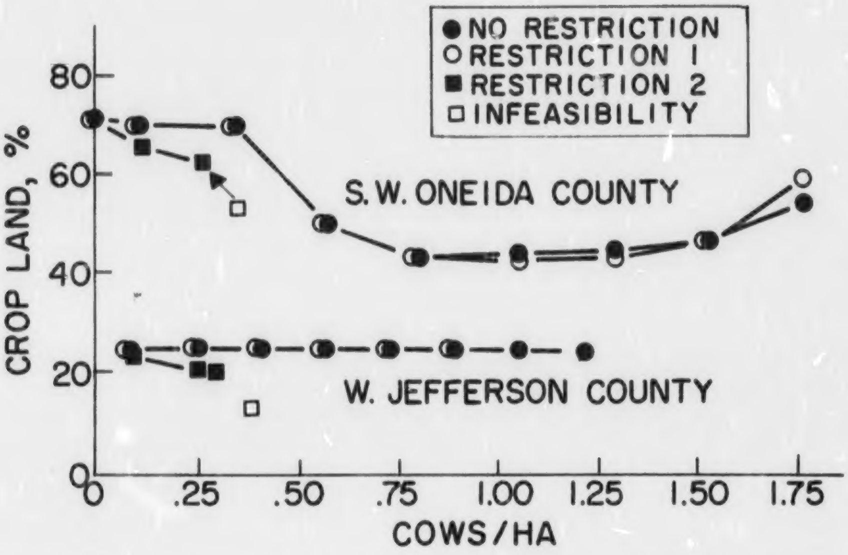

Figure 58. Corn grown as percent of cropped land - both counties.

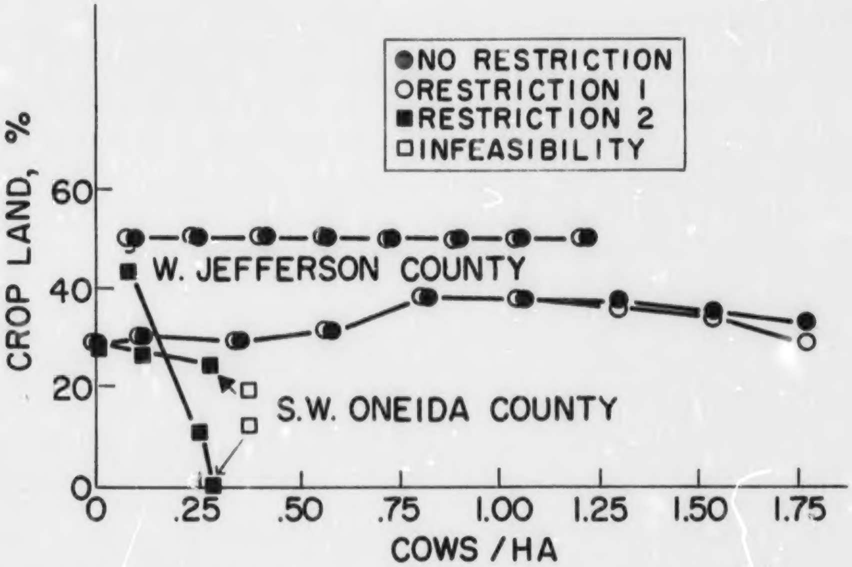

Figure 59. Alfalfa grown as percent of cropped land - both counties.

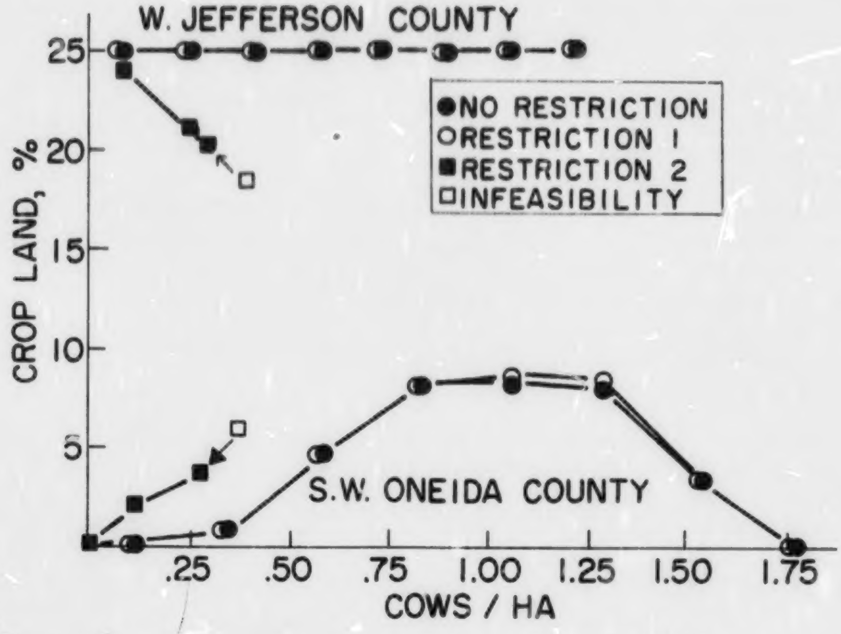

Figure 60. Oats grown as percentage of cropped land - both counties.

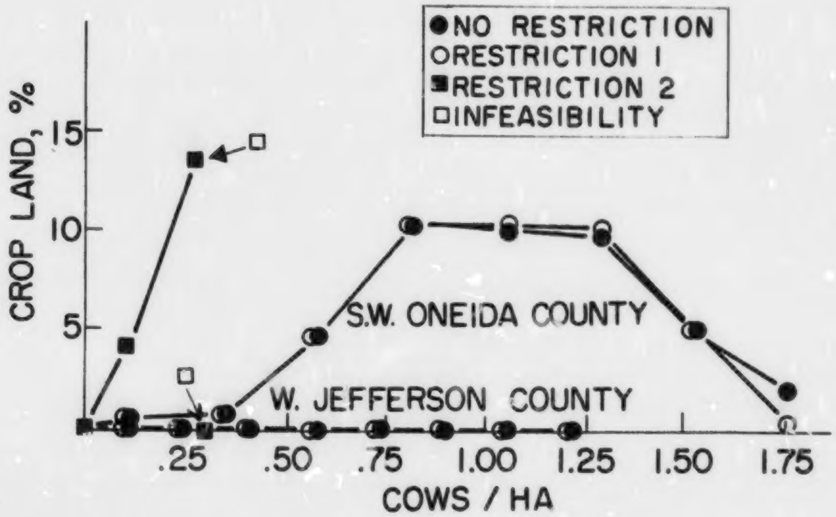

Figure 61. Wheat grown as percent of cropped land - both counties.

of corn-oats-wheat-alfalfa-alfalfa is substituted for the five years of corn and two years of alfalfa. At Restriction Level 1 there is no change from "No Restriction" until a herd size of 130 cows is reached, when an increase in land set aside for manure dumping is offset by a reduction in alfalfa and wheat acreages.

At Restriction Level 2 on the Oneida County farm, corn and alfalfa acreages drop as herd size increases beyond 10 cows. This reduction in acreage of corn and alfalfa is matched by a rapid increase in grass, and a smaller increase in oats and wheat. This results from the substitution of a corn-oats-grass-grass-grass and a corn-oats-wheat-alfalfa-alfalfa rotation for the five years of corn and two years of alfalfa. Again, as with the Jefferson County farm, the reason for this substitution is the need for crops which will accept manure at all seasons of the year except winter, since no dumping or manure is permitted at this level of restriction, and manure has to be stored over winter.

Figure 63 shows the changes which occur in the percentage of corn which is grown for silage instead of grain. These changes affect soil loss and runoff and will be referred to later. All corn at the Jefferson County location is grown for silage above a herd size of 50 cows. The reason for the changes which occur is the need to meet the home-grown forage requirement of the herd.

Runoff

Estimates of the runoff from the two farms are presented in Figures 64 and 65. The Oneida County farm has slightly more runoff at low cow/land ratios because of the greater acreage of cropland. However, there is very little effect on the runoff either from increasing herd size or from imposing restrictions. The reason for this is that the principal variable in runoff is the cultivated land factor, which is seen to vary little throughout the range of solutions in this location. In Jefferson County, however, there is a continuous increase in runoff as herd size increases due to the increasing amount of cropped land.

In Jefferson County, the runoff is increased by the imposition of Restriction Level 2. This follows as a result of the increase in cropped land which is necessary for manure disposal under the conditions of this restriction. Thus, it is seen that in a situation where crop production is generally unprofitable, as for example on poor soils such as those encountered in Western Jefferson County, a restriction requiring that manure be spread only where uptake of nutrients is possible, is likely to increase expected runoff. The

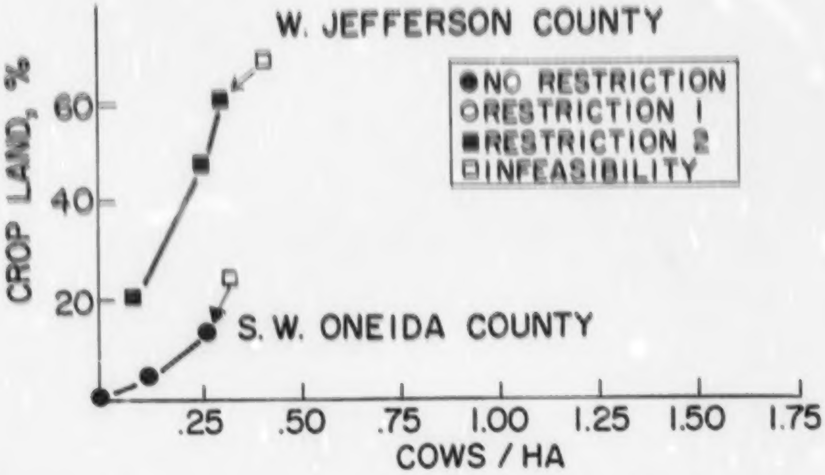

Figure 62. Grass grown as percent of cropped land - both counties.

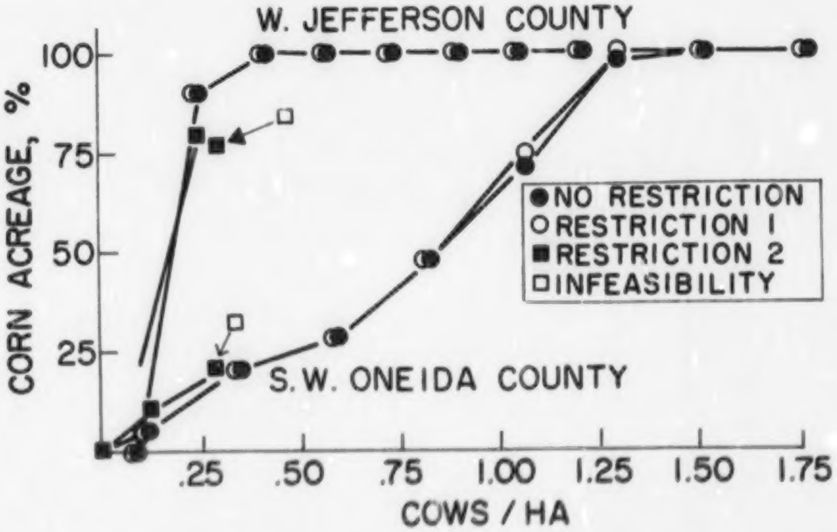

Figure 63. Corn silage grown as percent of corn acreage-both counties.

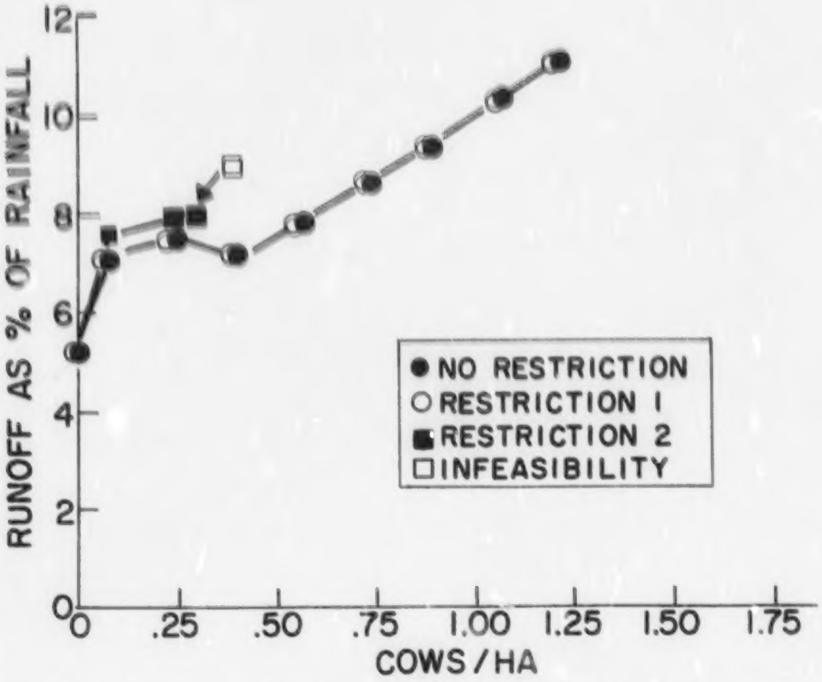

Figure 64. Runoff as percent of rainfall - W. Jefferson County.

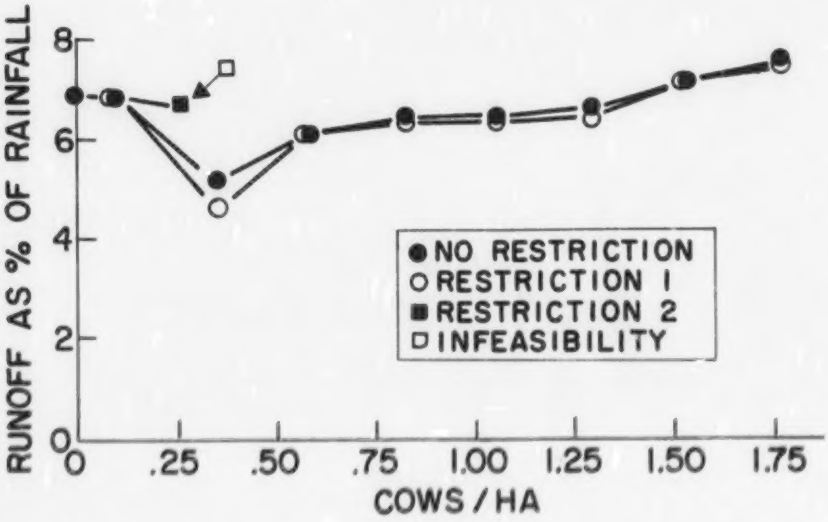

Figure 65. Runoff as percent of rainfall - S. W. Oneida County.

reason for this is the need for more soil to be cultivated than would be the case without the restriction.

Soil Loss

Two large differences in the expected soil loss from the two farms are evident from Figures 66 and 67. One difference is in the magnitude of the losses. The steeper slopes, and more erodible soils on the Oneida County farm, coupled with the large area of cultivated crops, lead to high soil losses compared with the Jefferson County farm. The other difference is in the slope of the curves, which show that in Jefferson County soil loss increases with increasing herd size. It can also be seen that Restriction Level 2, on the poor soil of Jefferson County, actually increases soil loss, which would appear to defeat the object of the imposition of this restriction.

The Oneida County soil loss tends to decrease with increasing herd size, because of the greater amount of manure spread on the cultivated soil areas, with a consequent drop in the erodibility of the soil as prescribed by the model. Restriction levels in Oneida County appear to have little effect on soil loss. The variability seen in the soil loss curves for "No Restriction" and Restriction Level 1 in Oneida County is misleading. It results from the fact that it is possible to arrive at two solutions to the maximizing procedure which both result in the same maximum net revenue, but which have different combinations of crops and soils. Although the model requires every year of each rotation to be represented on all soil areas used by that rotation, it is possible to select different soils for different rotations while producing the same economic returns. This results in different soil loss figures for two situations which might be identical in every other respect. Attaching a cost to farming sloping soils alone will not prevent this problem, as soils on the same slope may have different erodibilities. Only by placing an economic value on soil loss, thus forcing soil loss to be included in the objective function of the maximizing procedure, will this situation be avoided. However, it is almost impossible at the present time to place a meaningful value on soil loss in a model of this type. Any value which was used would also be unlikely to reflect the attitude of the farmer in his decision making, as farmers seldom attempt to place any direct economic value on soil loss. It was therefore decided to allow the computer to make activity selections without regard to soil loss, and to accept, as representative of actual conditions, any variability in parameter values which resulted from this decision.

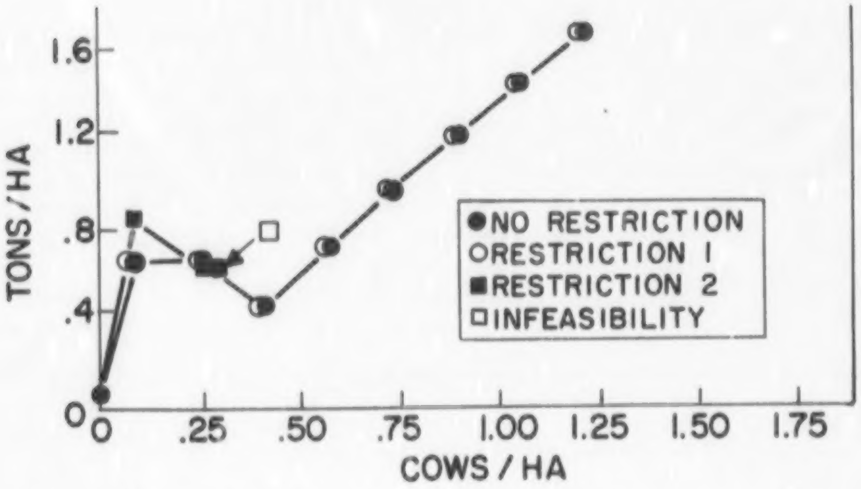

Figure 66. Soil loss - W. Jefferson County.

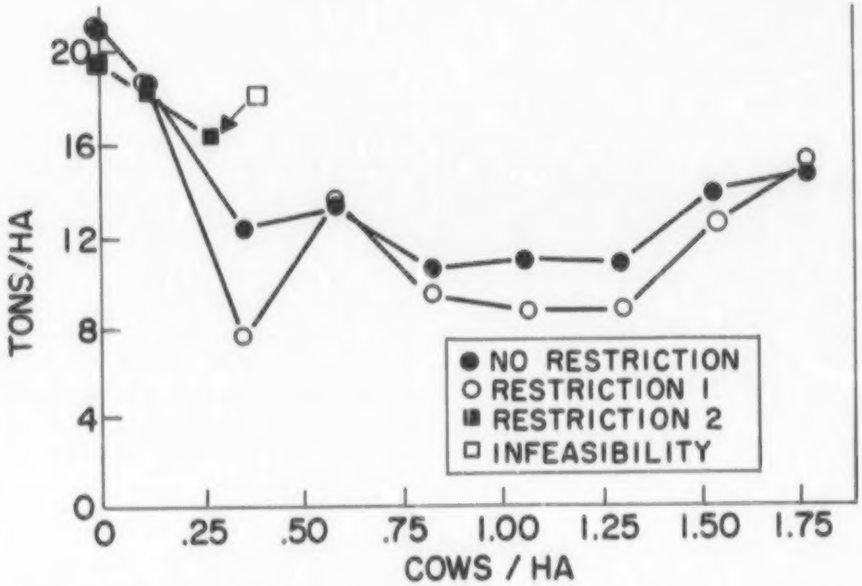

Figure 67. Soil loss - S. W. Oneida County.

The increase in soil loss at the high cow numbers in Oneida County appears to be the result of rotation changes in order to meet feed requirements. The corn crop, particularly corn grown for silage, has the highest overall soil loss rate of all the crops considered by the model, and the percentage of corn grown for silage was seen to increase with herd size on the Oneida County farm.

Total Potential Nitrogen Loss

The total potential nitrogen loss is that quantity of nitrogen which can be expected to be lost either in runoff, sediment or seepage, or volatilized as either ammonia (including storage loss) or as nitrogen gas from denitrification.

It can be seen from Figures 68 and 69 that the total potential nitrogen loss for Restriction Level 1, and where no restriction applies, closely follows the curve for soil loss (see Figures 66 and 67). At Restriction Level 2, however, this total loss of nitrogen is greatly reduced in both the regions studied. The reason for this is the high degree of control which this restriction level exerts over the amount of nitrogen which is applied to the soil. Thus the regulation preventing the application of more nitrogen than is needed by the crop, appears to be successful in having a positive effect on nitrogen losses in both counties. However, as will be seen later, all the individual components of this total potential nitrogen loss are not necessarily also reduced by Restriction Level 2.

Runoff Losses of Soluble Nitrogen

Runoff losses of soluble nitrogen are shown by Figures 70 and 71 to follow the same trends as the losses of runoff water (see Figures 64 and 65). However the increase in runoff which is seen, in Jefferson County, to result from the application of Restriction Level 2, does not lead to the same degree of increase in the loss of soluble nitrogen in the runoff water. Thus Restriction Level 2 is simultaneously increasing runoff and decreasing the amount of nitrogen in the runoff water. The net result is a general reduction in soluble nitrogen losses compared to that which is found when no restrictions are applied, or when Restriction Level 1 is imposed.

In Oneida County, Figure 65 shows that there is little change in runoff quantities as a result of imposing the restrictions. However, the effect of Restriction Level 2 is to reduce the concentration of nitrogen in the runoff, as is the case in Jefferson County, so that the runoff loss of nitrogen is actually reduced by the set of restrictions at Level 2.

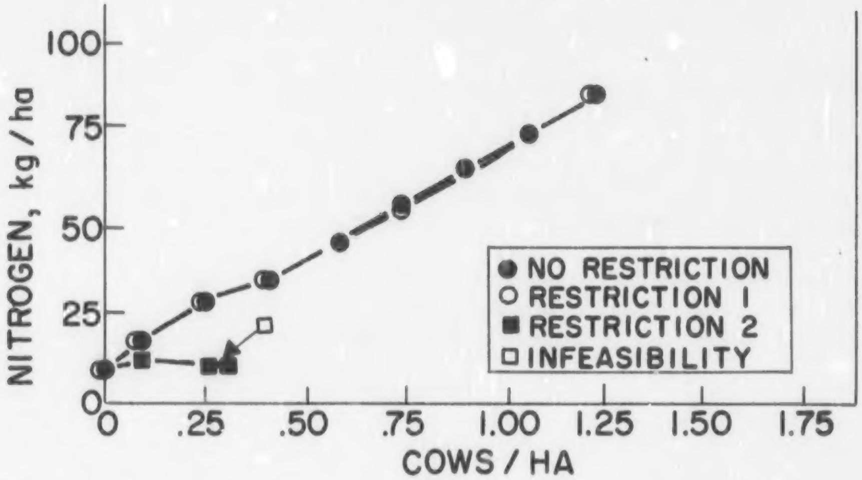

Figure 68. Total potential nitrogen loss - W. Jefferson County.

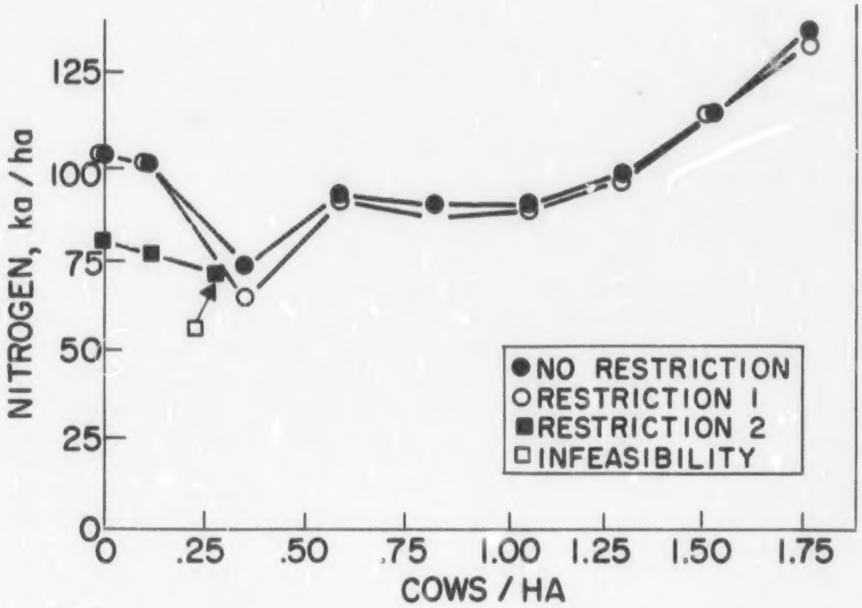

Figure 69. Total potential nitrogen loss - S. W. Oneida County.

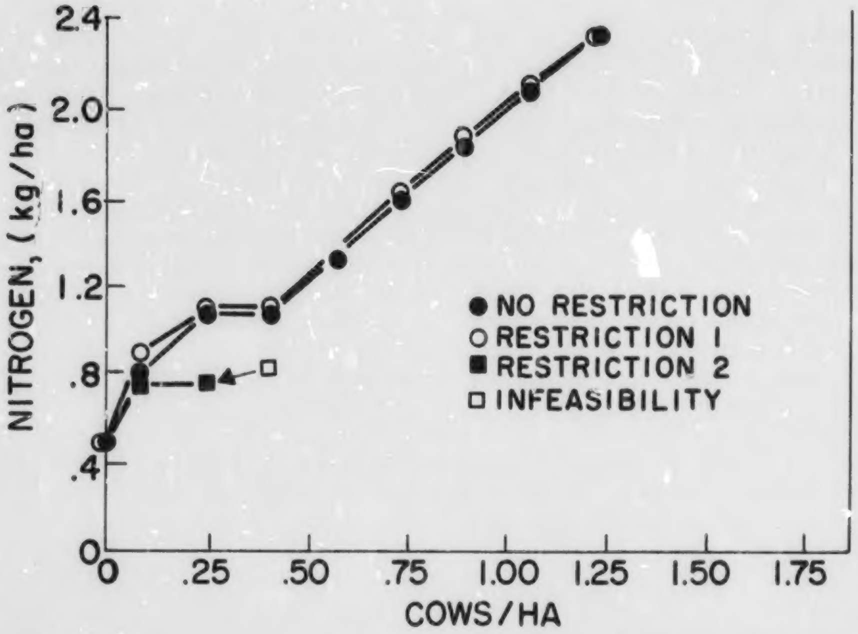

Figure 70. Soluble nitrogen loss in runoff - W. Jefferson County.

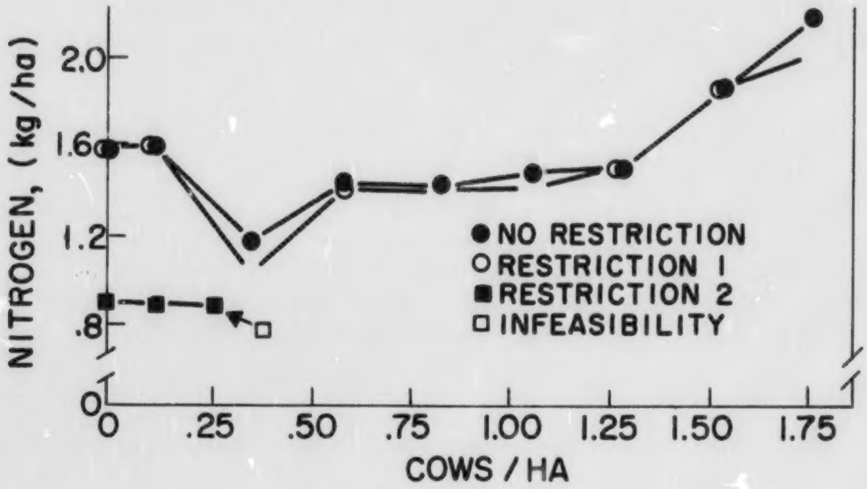

Figure 71. Soluble nitrogen in runoff - S. W. Oneida County.

Runoff Losses of Particulate Nitrogen

Particulate losses of nitrogen in eroded soil carried by runoff, are presented in Figures 72 and 73. Predictably, these losses are closely related to soil loss. Unlike soluble nitrogen, there is no great reduction in particulate nitrogen when Restriction Level 2 is applied. This implies that the restrictions are more effective in controlling soluble nitrogen loss. This can be explained by considering the effect of the restriction on the model as it relates to these losses. The total quantity of nitrogen in the soil, both organic and inorganic, is large, and thus any practice which changes the amount of total nitrogen in the soil must make a large magnitude of change in order to have a significant effect on total soil nitrogen. However, the amount of soluble nitrogen in the soil at any one time is relatively small, so that a change in practice affecting mainly the soluble fraction of the soil nitrogen, does not have to be great in order to have a significant effect on the total soluble nitrogen.

Thus it is seen that particulate nitrogen is hardly reduced by Restriction Level 2, whereas soluble nitrogen is considerably reduced by this restriction. The reason for this is that eroded soil material carries all forms of soil nitrogen with it, while runoff losses of soluble nitrogen are only affected by the soluble nitrogen in the soil.

Percolation and Denitrification Losses of Nitrogen

The reason for combining the percolation losses of nitrogen together with denitrification as one loss, is because there is no effective way to separate them. The model calculates this combined value by difference. To separate the denitrification loss from that quantity of nitrogen which must be assumed to pass through the soil into the ground water, is almost impossible at this time.

It is evident from Figures 74 and 75 that the effect of Restriction Level 2 on the combined percolation and denitrification losses of nitrogen is pronounced in both regions studied by the model. In Jefferson County, Restriction Level 1 had no effect compared with the unrestricted solution. In Oneida County, there is an apparent increase in these combined losses when Restriction Level 1 is applied, but the variability in the soil losses makes it impossible to determine the significance of this apparent increase.

Particulate Phosphorus Loss

As was discussed, the losses of soluble phosphorus in runoff and

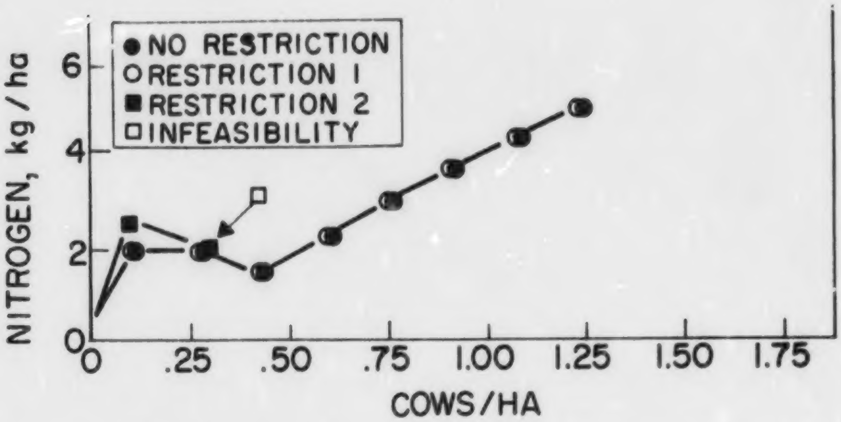

Figure 72. Particulate nitrogen loss - W. Jefferson County.

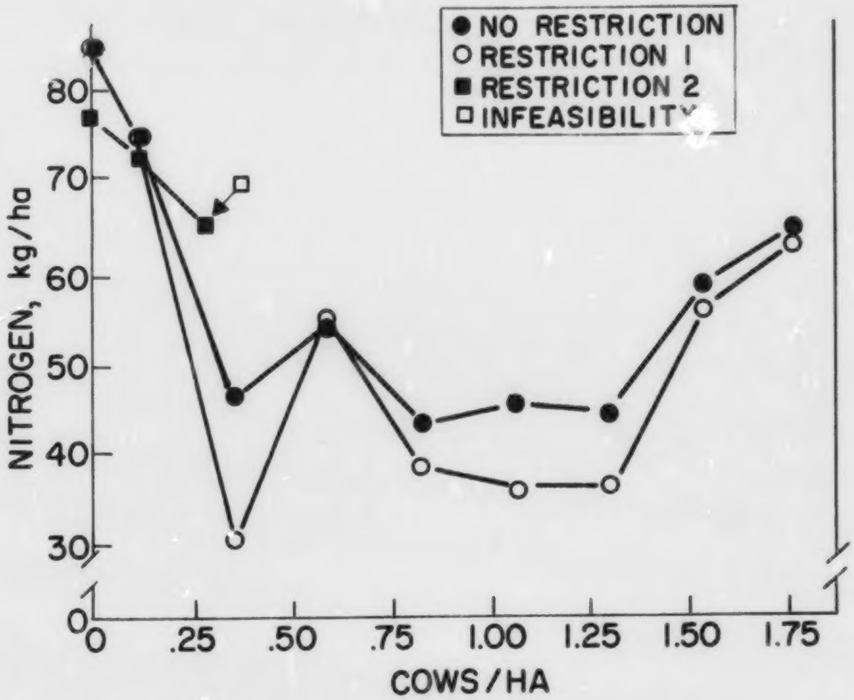

Figure 73. Particulate nitrogen loss - S. W. Oneida County.

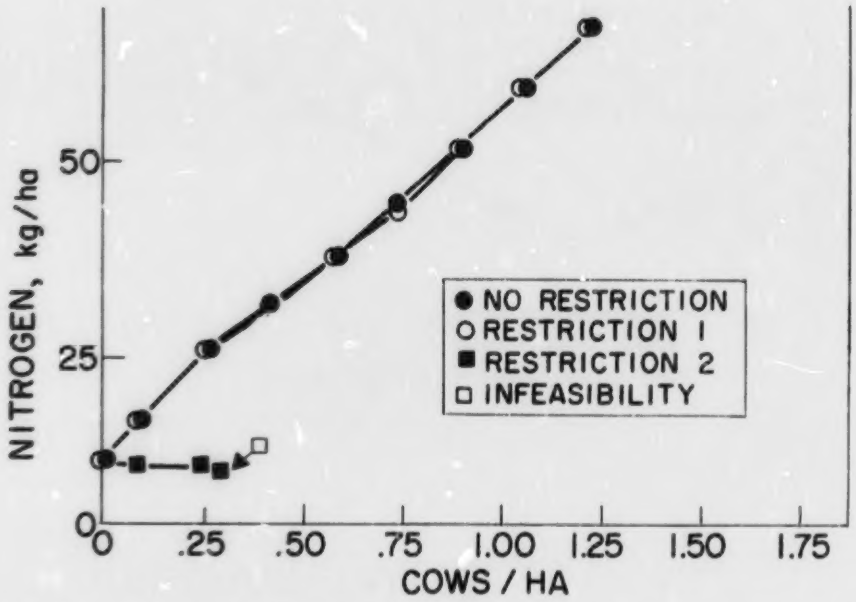

Figure 74. Nitrogen loss by percolation and denitrification - W. Jefferson County.

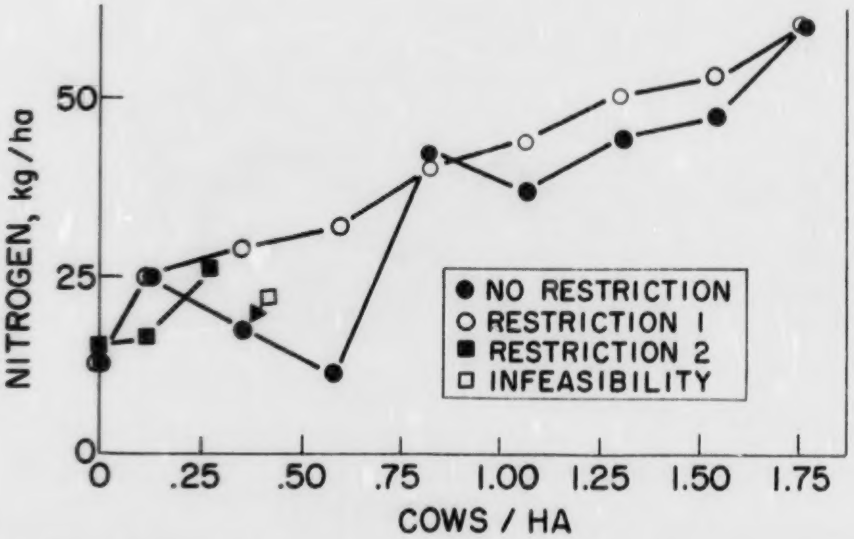

Figure 75. Nitrogen loss by percolation and denitrification - S. W. Oneida County.

seepage water are both unpredictable and essentially small. This does not mean that they are not important - and it may eventually be shown that soluble phosphorus (from all sources, not just agriculture) rather than soluble nitrogen, is the principal cause of eutrophication in receiving waters, even if only in very low concentrations. However, to include estimates of soluble phosphorus losses in this model at this time would only serve to impair the credibility of the whole model. Further research may indicate more reliable methods of predicting soluble phosphorus movement than are currently available.

Particulate phosphorus losses have been estimated and these are presented in Figures 76 and 77. These losses follow very closely the trends seen in the soil loss curves of Figures 66 and 67. As has already been discussed relative to nitrogen losses, the reason for the small effect of the restrictions on particulate losses is the relatively small influence which changes in nutrient applications have on the total amount of the nutrient in the soil. This applies to phosphorus as well as nitrogen, and so the curves for particulate phosphorus are also very similar to those of soil loss.

Other Relevant Parameters

There are many other factors which may be studied with the use of this model. Only those of interest to the particular subjects of legislation and agronomic and manure management practices have been presented.

GENERAL DISCUSSION

The assumptions of the physical nature of the farm have an effect of the two locations. The two hypothetical farms were of different sizes, but the distances used for zone classification in the hypothetical legislation were the same for both farms. This means that the proportion of the land area of each farm, which is included in the controlled manure spreading zones, is different. This difference contributes to the fact that the Jefferson County farm became infeasible under Restriction Level 2 at 35 cows, while the Oneida County farm became infeasible at only 23 cows.

Some of the other assumptions and simplifications used in this study require further discussion in relation to the results which have been presented. The assumption dealing with linearity of crop growing and machinery costs, for example, is an assumption which probably results in the costs per unit area, at low acreages, being assumed to be lower than they might be in reality. Thus the "net revenue" observed at low herd sizes in the Jefferson County location

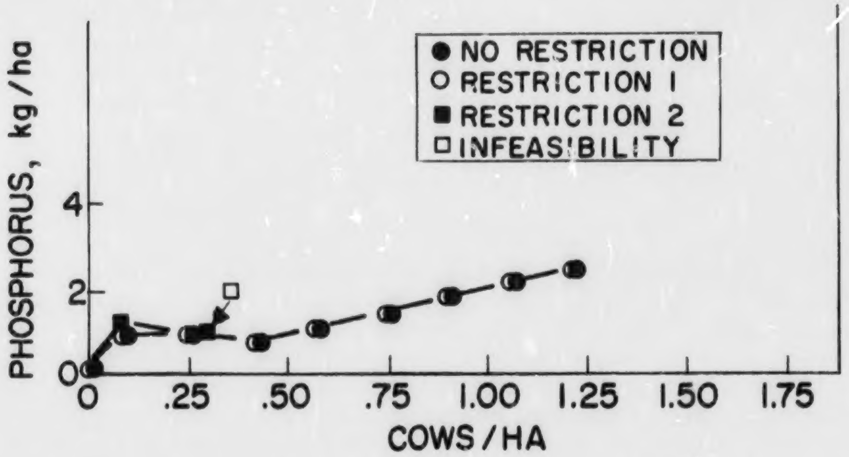

Figure 76. Particulate phosphorus loss - W. Jefferson County.

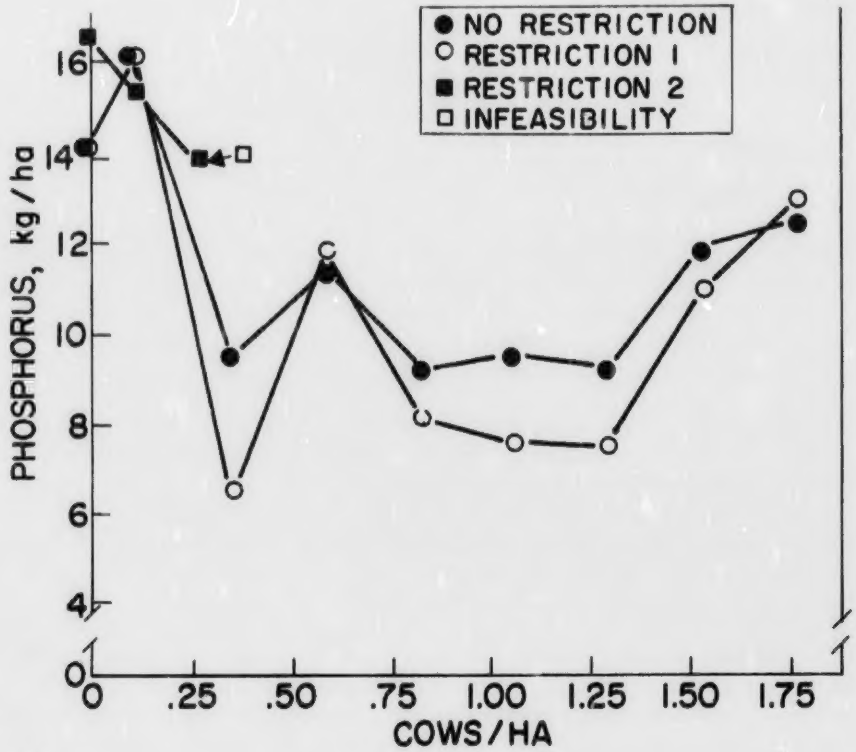

Figure 77. Particulate phosphorus loss - S. W. Oneida County.

is probably slightly overestimated. Similarly, at the largest herd sizes in Jefferson County, the "net revenue" may be slightly underestimated as a result of this assumption. The crop acreages in the Oneida County location were seen to vary less than in the Jefferson County location, and the assumption of linearity of crop growing costs is unlikely to have any pronounced effect.

Another simplification which affects the results is that associated with the loss of ammonia nitrogen volatilized from storage. The effect of this simplification is only applicable to the results under Restriction Level 2. It has the effect of reducing the herd size which can be reached before infeasibility occurs, as nitrogen disposal is the limiting factor in manure disposal at this restriction level.

The reason for this is that the manure application rates are calculated based on the nitrogen available to crops, e.g. after ammonia volatilization. The simplification used here assumes that a portion of the winter manure ammonia is available to crops, depending on the time at which it is spread, whereas it is actually volatilized from storage and is not available. Thus the summer and fall application rates used are slightly lower than would be strictly allowable under Restriction Level 2. It is estimated that this simplification had no effect on the Jefferson County farm, as almost all stored manure was spread in the spring at the infeasibility point. On the Oneida County farm, all stored manure was spread in the fall, and a herd size reduction of about 4% (or 0.9 cows) occurred at infeasibility. While this simplification has been used here without any great effect on the results, it is probable that some alternative method of handling ammonia volatilization before manure is spread should be devised if any treatment or other high-ammonia-loss handling method was to be included in the study.

Another simplification which may effect the results is that of a single management level. It is probable that the results on the Jefferson County farm would be more similar to those of the Oneida County farm if the level of management was assumed to be higher in Jefferson County. It would be generally true to state that the soils of Western Jefferson County need better management than the more productive soils. If given this better management, they may be almost as productive as those soils in Oneida County which produce high yields without high levels of management capability.

It is difficult to determine, with any degree of certainty, which of the legislative controls is most limiting, at any given herd size, in terms of the farmer's ability to increase his income. The reason for this difficulty is partly due to the nature of the controls, and partly due to the nature of the model. For example, it will be seen from Table 37 that, at Restriction Level 2, land is being zoned for "no manure applications" by both the distance from surface water control, and the distance from dwellings and public access control. Thus it is impossible to determine which of these two controls is limiting. Similarly, it can be seen that since the manure application rate control (control parameter 1) reduces the quantity of manure which can be spread on that land which is available for disposal, there is a consequent need for more "disposal" land at the same herd size. However, more land on which spreading may be done may not be available because of the distance from water and public access controls. Thus again it can be seen that it is impossible to determine which of these controls is limiting the farmer's income the most. The control in Table 37 which requires certain minimum land areas to be owned or controlled per animal kept on the farm was, in all instances in this study, of no effect. Herd densities never reached the control limit, either because the herd size never became large enough, as in the case of the control of Restriction Level 1, or because infeasibility occurred before the herd size limit was reached, as was the case at Restriction Level 2.

In both locations it was seen that there was very little change in "net revenue" when Restriction Level 1 was imposed compared to the situation where no restriction applied. It was also evident that the expected losses of nutrients to the environment were not affected by Restriction Level 1 either. However, it should not be overlooked that there were a number of unmeasurable benefits from Restriction Level 1, such as the elimination of manure spreading within certain limits of dwellings and public roads. It would appear, then, that these benefits were gained at very little cost to the farmer, within most of the range of herd sizes used in this study. At the last two herd size increments in the Oneida County location, a drop in revenue was observed at Restriction Level 1. Thus it is likely that on the Jefferson County farm the imposition of Restriction Level 1 will reduce the farmer's potential income at some herd size greater than 150 cows.

At Restriction Level 2 the requirement that the storage should be located at least 151 m (500 ft) from the barn and farm dwellings was met without affecting the net revenue. This was because there was no land less than 151 m (500 ft) from the barn on which spreading was permitted so that the transportation cost to a zone at least 151 m (500 ft) from the barn was necessary with or without this requirement.

The shadow prices for the different soil type areas indicate that land which cannot be used for manure spreading would add nothing to revenue if increased on the Jefferson County farm at any restriction level. On the Oneida County farm this land is worth about $42-84 per hectare in terms of increase in revenue if there was a one acre increase in the most productive soil, depending on herd size. At the point where the solutions become infeasible at Restriction Level 2, land on which manure can be spread has its highest shadow price. The shadow prices indicate that the land in the second distance zone from surface water, that on which manure spreading on sod crops is allowed, is less valuable than the unrestricted land. However, the difference between the shadow prices of this land and the unrestricted or the completely restricted land indicates that, except at the point of infeasibility, it would add more to the revenue of the farm to transfer one hectare from partially restricted (spreading allowed on sod) to unrestricted, than to transfer one hectare of completely restricted soil to the partially restricted zone. Thus it can be said that the difference between allowing spreading of manure on sod, and allowing no spreading at all is less than the difference between allowing spreading on any crop and allowing spreading only on sod crops. This is true of both locations prior to infeasibility. The situation is reversed at the point of infeasibility, because at this point, the ability to spread any manure at all becomes of great importance to the solution.

It must be considered, then, when deciding on the benefit of prohibiting manure spreading within a certain distance of surface water, that any environmental benefit which results would probably cost the operator of the farm more, in terms of lost revenue, than prohibiting manure spreading on all crops other than sod. However, it should be remembered, when deciding the boundaries between these two restrictions and the unrestricted land, that a change in the boundary between "no spreading" and spreading only on sod crops, will probably have a lesser effect on farm income than a similar change in the boundary between the unrestricted zone and that in which manure spreading is allowed only on sod, providing that the farm is not at the point of infeasibility, which is unlikely.

SECTION VI

A COMPARISON OF (I) CONVENTIONAL AND (II) IMPROVED DAIRY WASTE MANAGEMENT ON TWO HYPOTHETICAL DAIRY FARMS

Private enterprise has given little or only limited considerations to the environment. During the past five or six years, EPA and other agencies have made an effort to point out the need for protecting and improving our environment. It is said by many that this protection and improvement of the environment must be done at the expense of the individual or society. It does not necessarily follow that society or the individual--in our case a dairy farmer--must find it unprofitable to carry out such operations.

The above statement of a concept has been brought about because of the fact that the public understanding of energy conservation and ecologically sound waste management is changing. There is a new appreciation of the value of all organic waste as fertilizer. There is a new addition to farm management programs which has only recently become widespread. Prior to the present time, it was comparatively easy for a farmer to supplement his plant nutrient needs by the purchase of commercial fertilizer at a very low price. This price was in comparison to the relative cost of other materials involved in the farming operation. (See Table 39).

Table 39. COMPARATIVE PRICES PER KILOGRAM FOR FERTILIZER NUTRIENTS DELIVERED AT THE FARM. 1970 VERSUS 1975 (PROJECTED (80))

Year	N	P_2O_5	K_2O
Jan. 1970	.11	.17	.09
Jan. 1975	.73	.37	.22

The national impact of this economic circumstance was that animal manures on the farm were regarded as a major disposal problem. This problem inferred that there should be no interference with the environment and that, in fact, public money or private money would have to be spent to make sure that the animal manures would be properly handled to insure no environmental damage. The broader energy picture has become apparent only within the last year. The fact that it takes a very considerable amount of energy to produce fertilizer nutrients has up until now not been widely appreciated. The costs of nitrogen in terms of energy can be realized when it is remembered that one kilogram of synthetic nitrogen is the equivalent of approximately two kilograms of diesel fuel in terms of energy (82). Nitrogen has been produced synthetically by manufacturing anhydrous ammonia under the catalytic process of uniting hydrogen and nitrogen using the energy of natural gas. With the shortages and increased price of natural gas, the price of nitrogen has necessarily been increasing. (See Table 39) Based on nutrients as fertilizer, one metric ton of free stall dairy manure was worth $1.18 in 1970 and is projected to be worth $4.67 in 1975.

GENERAL MANAGEMENT DECISIONS ON NUTRIENT RECYCLING ON THE DAIRY FARM

In addition to growing the feed for the dairy animals, each dairy farm needs to have a proper soil balance of mineral nutrients. This is necessary to maintain high crop yields on the dairy farm. This presentation is given to illustrate the nutrient recycling on a dairy farm. It is schematic for those portions of the dairy industry where experimental data from this project has not been collected. We have used representative information from the literature in order to make the character of the decisions more realistic. A one-hundred cow dairy is assumed. This size of dairy is maintained by approximately two-thirds of a cow per animal in calves, young stock, and heifers in order to maintain the milking line of cows. For sake of convenience, we will say that there will be 160 animal units in our working dairy.

All practical options considered are those already utilized in New York State. A farm of approximately 146 hectares of tillable land is a convenient size to consider for this operation. Additional hecteres of cropland and/or pasture land are also possible. Such land additions would depend upon the permanency of the program. It is assumed that there is a (I) conventionally managed, and (II) "improved" managed dairy farm. They are identical in numbers and kinds of animals and also in land resources. Difference between (I) and (II) are developed as a result of land resource management, cropping practice, and manure management.

Each milking cow or dry cow or heifer which make up the total population of 160 animal units will require a necessary amount of feed per animal unit. This is six metric tons of hay equivalent per animal unit (84). While this six metric tons of hay equivalent per animal unit is adequate for calves, heifers, and dry cows, milking cows will require 1270 to 1525 kilograms of corn plus concentrate.

First, the management conditions for (II) improved management will be discussed. One can make the assumption that the animals will be fed for their total six metric tons of hay equivalent three metric tons of dry matter in the form of corn silage and three metric tons of dry matter in the form of haylage. They will be fed grain in the form of 1300 to 1500 kilograms of grain. In addition, a protein supplement will be purchased. On 160 animal units one then arrives at a total of 146 hectares of land to produce the total corn and alfalfa needed to sustain the cows. In addition, 18 hectares of wheat will be grown. This wheat will yield approximately 40 bushels per acre. It will also produce 4.5 metric tons of straw per hectare. One is obliged in order to maintain this ratio of crop use on the land to leave the alfalfa intact for three years and to grow corn for four years in the rotation. Each year 18 hectares would be taken out of alfalfa and plowed for corn. Each year 18 hectares of corn land would be seeded to alfalfa. Also 18 hectares of corn land will be seeded to wheat. (See Table 40)

In order to maintain the soil structure to maximuze the inputs of organic matter and to minimize the energy inputs, the following system of management with respect to corn would be utilized. During the first year after alfalfa, the corn would be grown in a no-till situation. After wheat, corn will also be grown in a no-till situation. Red clover having been seeded in the wheat. Assuming that the farm was in all alfalfa, the first year would see no-till corn planted on 73 hectares, of which, 36 hectares of corn would be harvested for silage. Early varieties would be utilized both for silage and for grain. It is assumed that the silage yield would approximate 16 metric tons per acre per year. It is further assumed that the grain

Table 40. SCHEMATIC REPRESENTATION OF CROP ROTATION FOR MAXIMIZING SOIL STRUCTURE IMPROVEMENT AND DAIRY MANURE RECYCLING.

Year	Field Designation Number [a]							
	1	2	3	4	5	6	7	8
1974	C	C	W	C	C	A	A	A
1975	C	W	C	C	A	A	A	C
1976	W	C	C	A	A	A	C	C
1977	C	C	A	A	A	C	C	W
1978	C	A	A	A	C	C	W	C
1979	A	A	A	C	C	W	C	C
1980	A	A	C	C	W	C	C	A
1981	A	C	C	W	C	C	A	A

[a] Each field is 18 hectares

C = corn; W = wheat; A = alfalfa

corn yield would approximate 5000 kg/ha/yr. If desired, the fodder from the grain corn may be removed and shredded and used for bedding for the young stock. Winter wheat will be seeded after silage removal. This will make wheat straw available for bedding as well. As soon as the corn has been removed for grain, rye will be seeded directly into the no-tilled plots. The corn for grain will be planted in the second year after alfalfa and wheat. If the stover from the grain harvest is not used for bedding it will be chopped and left on the land and plowed down for wheat and alfalfa respectively. Wheat would be seeded in the fall and alfalfa would be direct seeded in the spring.

Conventional Management

The exact practices that a "conventional" dairyman would use in crop production and soil management are not known. They could be determined on the basis of a survey. The information presented here is based on observations in New York State.

In general, crop rotations are not rigorously followed. Areas close to the dairy barn are usually planted to continuous corn. Wheat is not generally grown. Alfalfa is planted at a greater distance from the dairy barn. It is assumed that this alfalfa will remain in hay until it is "run out." Bedding is generally not provided for in the cropping program, but is obtained where possible.

Manure Management

The following presentation concerns the general situation and (II) improved management. The 100 milking cows will be housed in a free stall "cold barn." The barn will be equipped with a delta scrapper and a urine channel (43, 83). This urine channel will make it possible to collect and store 290 metric tons of urine annually. This urine will be used for side dress on 73 hectares of corn annually. It will also be used to top dress wheat in the spring. Rates or corn will be 3.36 metric tons of urine per hectare, 50 kg of N and 50 kg of K_2O per hectare. Wheat will be top dressed at the rate of 2.2 tons/ha (34 kg/ha of N). Approximately 1180 metric tons of slurry manure will be generated during the year by the 100 milkers. Eight hundred metric tons of this material will be hauled into temporary especially constructed storages close to the fields where it will be applied to 36 hectares of corn at the rate of 18 metric tons per hectare immediately before spring plow down.

The wheat straw will be used to bed down calves, young stock, heifers, and dry cows in a pen stable. These animals will compact and preserve this manure. Eight hundred metric tons will be transported immediately from the pen stable to the corn field immediately before plow down.

The approximate 360 metric tons of slurry manure from the milkers not needed for corn will be spread on the 18 hectares of wheat late in the fall.

Conventional Handling -

The milkers will be housed in a "cold" free stall barn. Manure will tractor scraped to a lip and spread daily on continuous corn land. Calves, young stock, heifers, and dry cows will be bedded with as little straw as possible. This manure will also be spread on corn.

Environmental Benefits of Improved (II) Over Conventional (I) Management

The research reported here shows in general that:

1. Well-maintained soil structure looses approximately only half as many nutrients to the environment as poorly-maintained soil structure. Conventional management (I) has 73 hectares of poorly-managed corn in contrast to 73 of (II) well-managed corn.

2. The lowest rate of nutrient losses were obtained from immediate plow down in the reported research. This is being practised in II. Storage is discussed in references 43 and 83.

Benefits to the Farmer of Improved (II) Over Conventional (I) Practice

Improved management (II) will very likely use a Logoon for milking center waste (85). This may supply limited nutrients wasted under (I). Both management systems will produce 1960 metric tons of manure. Using the 1975 values of Table 39, one arrives at $7,200 for N, $1,756 for P_2O_5 and $2,160 for K_2O. One can assume that improved management saves 75 percent of N, 90 percent of P_2O_5 and 75 percent of K_2O. Similar values for conventional management would be 30 percent for N, 70 percent P_2O_5 and 30 percent for K_2O.

In terms of dollar value return on the manure, we would have approximately $4,000 for conventional versus $9,000 for improved management. If one uses the cost data of Jacobs and Casler (81) for conventional handling, one has a cost of $42 per cow. If one uses their cost per cow for a liquid system, one has a cost of $64 per cow. It is assumed that the added costs of urine handling and low cost outdoor storages would equal those of the liquid system. Thus the cost per cow for 100 cows would be $22 more or $2200. Approximately $2500 would be saved each year on fertilizer costs. It is assumed the calves, young stock, heifers, and dry cows would have the same manure handling costs.

SECTION VII

SUMMARY

The following is a summation of the research findings dealing with the land application of manure and the results obtained from the linear programming model.

Dairy manure disposal consisted of a single land application to field plots during the winter, spring and summer at rates of 35, 100 and 200 metric tons/ha. Each time and rate of application appeared on both a well managed soil (return of crop residues) and a poorly managed soil (removal of crop residues). This plan made it possible to demonstrate the influence of the past 16 years of soil management practice and the present dairy manure treatments on nitrogen and phosphorus losses from the land. Nutrient losses were measured for the three rates of application in surface water effluent and in sediment but only for the 35 and 200 t/ha rates for tile effluent.

Manure applications began with the winter treatment in February 1972. January 1, 1972 was chosen as a starting point in the calculations of annual losses of inorganic nitrogen and total soluble phosphorus in surface water and tile effluent and total nitrogen, total phosphorus in the sediment. The data presented are the results of all sample producing runoff and drainage events as derived from natural rainfall. In one instance, a rainfall simulation (irrigation) study was conducted on a single treatment in order to investigate nitrogen and phosphorus losses with time during a drainage event.

Annual nutrient loss comparisons were made for 1972 and 1973. Nutrient losses for entire 1974 have not been completed to date.

The 1972 calendar year in the northeastern United States was extremely wet. Precipitation was 67% above 'normal.' A tropical storm in June caused considerable rainfall and flood damage. Due to an abnormally wet year, results presented for 1972 may be a somewhat atypical array of the nutrient losses that may be expected under a more normal weather pattern. The data is extremely meaningful in demonstrating the magnitude of nitrogen and phosphorus discharges that can occur under adverse weather conditions. Annual precipitation during 1973 was only 2 cm above 'normal' and nutrient losses during this year may be more nearly typical of what can be expected.

ANNUAL NUTRIENT LOSSES

Surface runoff discharges of inorganic nitrogen and total soluble phosphorus showed a marked difference, for all treatments, between 1972 and 1973. The average increase in 1972 over 1973 was 750% and 340% for nitrogen and phosphorus, respectively. This clearly indicated that weather conditions are the most influential variable in studying nutrient losses. Regardless of the time and rate of dairy manure applications, nutrient discharges were a direct function of the intensity and duration of a climatological event.

With regard to annual nitrogen losses in surface runoff, the spring application and subsequent plowdown of manure proved to be superior over applications made in the winter or summer during a wet year (1972). The winter application during the same year yielded the greatest loss of nitrogen mainly due to the influence of a single snow melt event. Differences among the timing of manure applications for a more 'normal' climatological year (1973) were insignificant. The intermediate rate of application (100 t/ha) resulted in the greatest losses of nitrogen during both years. The 100 t/ha rate treatments are not tile drained and tend to exist on the more erosive plots, accounting for the greater discharges. Throughout the course of the experiment, the lowest rate of application (35 t/ha) yielded the lesser discharge of nitrogen in surface runoff. The highest rate of application (200 t/ha) resulted in nearly twice the discharge of nitrogen in comparison to the lowest rate during both 1972 and 1973.

Phosphorus discharges in surface runoff were similar to nitrogen with regard to treatment effects. Annual losses of total soluble phosphorus proved to be significantly greater for the winter application during both years. Phosphorus losses resulting from the spring and summer disposal periods were essentially identical. With reference to the rate of application and annual discharge of phosphorus, the 35 t/ha application rate produced a significantly lower discharge than the 100 and 200 t/ha treatments. The latter two rates of application exhibited similar phosphorus losses in 1973, but during the wet year of 1972, the 100 t/ha rate produced the greatest discharge, for reasons previously explained for nitrogen.

A soil structure variable (good versus poor) proved to be very influential. Well managed soils had significantly lower nitrogen and phosphorus discharges in runoff especially during an abnormally wet year in comparison to poorly managed soils. Well managed soils (return of plant residues, e.g. corn for grain) were superior to poorly managed soils (removal of plant residues, e.g. corn for silage) because of improved soil structure. Improved soil structure enhances infiltration and water transmission through the soil profile. In both 1972 and 1973, surface runoff was twice as great on poorly managed plots.

The addition or removal of plant organic residues (it has persisted in these plots for the last 17 years) as it influences soil structure may become erased in future years by the larger additions of organic matter from manure. Even if this characteristic is masked by future manure additions, the physical presence of a plant residue cover on the soil surface after harvest, on the well managed plots, would aid in the reduction of surface runoff.

Annual total nitrogen and total phosphorus losses in soil sediment, similar to nutrient discharges in surface runoff, was highly variable from year to year. Average nitrogen and phosphorus contents in sediment were approximately 63% and 43% greater, respectively, in 1972 as compared to 1973, mainly associated with increased rainfall and runoff in the former year. The timing of manure disposal showed a very limited influence on nutrient discharges in sediment for both years. Increasing increments of manure rates significantly increased nitrogen and phosphorus losses during 1972, but the relationship did not hold in 1973. In the latter year, the 100 t/ha rate had a significantly higher discharge of nitrogen and phosphorus. The loss of these two nutrients in both years was directly correlated to the loss of organic matter in sediment.

Soil management exhibited a significant influence on sediment losses. Plots that were poorly managed showed an approximate 250% and 360% increase in nitrogen and phosphorus discharges, respectively, in comparison to well managed soils.

In discussing runoff and sediment losses of nitrogen and phosphorus on an annual basis, some inconsistency was evident, especially when considering nutrient losses as affected by the rate of manure application. The 100 t/ha rate appears to be the treatment that was out of place when considering losses relative to 35 and 200 t/ha. This inconsistency is evident for many reasons.

Much of the increase due to the 100 t/ha rate in surface runoff during 1972 was due to an interruption in the disposal schedule during the winter. Unlike the 35 and 200 t/ha treatments, the 100 t/ha rate was delayed due to adverse weather, and was spread on dense melting snow in February, a condition not condusive to nutrient conservation, but none the less undoubtedly exists in actual farming situations. This surface soil condition resulted in unfavorable nutrient losses and raising upward the losses due to the 100 t/ha rate and the winter application relative to the other two rates of application. In addition to this condition, the 100 t/ha treatments were not existent on tile drained plots and although they were randomized, they tended to be associated with the more poorly drained plots of the experiment. This condition is reflected in the runoff and sediment losses relative to the two other rates of application. This phenomena should not be dismissed as too complex. Soil heterogenity is commonplace in any watershed, and results of a given treatment under given climatological references will vary with soil characteristics.

Annual tile discharges were studied for the three disposal periods for two rates of application (35 and 200 t/ha). The quantity of nitrogen and phosphorus in tile drainage was not a reliable indicator of the quantity that will eventually find its way to the ground water reservoir. Artificial internal drainage alters the natural pathways of water and consequently nitrogen and phosphorus movement.

From a statistical viewpoint, taking into acocunt the variability of annual quantities within replications, discharges of nitrogen and phosphorus were not influenced by the timing or rate of manure application, nor the soil management practice.

SELECTED RUNOFF EVENTS

The design of manure management schemes for an 'average' year, in terms of climatic events is difficult to assess since an average year exists in definition only. In the same sense, no two climatic events will be the same nor will the antecedent conditions pertaining to them be the same.

A series of selected runoff events were chosen to compare the relative behavior of manure treatments for a given climatological event. This becomes meaningful since a good many of the independent influences concerning nutrient discharges are acting similarly. Runoff events were chosen on the basis of the type of climatological event and to give a broad spectrum over seasons.

A snow melt event in February of 1972 served to illustrate the necessity to avoid spreading of manure on melting snow. The 35 and 200 t/ha winter rates were applied on frozen soil void of snow. The 100 t/ha rate was delayed due to a snow storm. Ten days later it was applied on melting snow. The data clearly indicated that manure disposal during active thaw periods can result in extremely excessive nutrient losses and high nutrient concentrations. However, low and high rates of application (35 and 200 t/ha) disposed on frozen soil and then covered with snow before a thaw period may result in acceptable losses especially at the lower rate of application. As an example, the inorganic nitrogen loss from 100 t/ha was 46 kg/ha, and 1 and 8 kg/ha for the 35 and 200 t/ha rates, respectively. The lower rate of application resulted in nitrogen and phosphorus losses less than areas that received no manure at all (plots that would receive the first application of manure in the spring and summer). When the excessive losses from the 100 t/ha rate, a function of the time of application during the winter and not the rate per se, are accumulated over a period of time, this one runoff event places the nutrient losses from 100 t/ha out of phase relative to the 35 and 200 t/ha rate, and the winter application out of phase relative to the spring and summer applications.

Hurricane Agnes in June 1972 caused considerable flooding and damage to the eastern seaboard. The general behavior of nutrient losses for this runoff event were quite erratic for the rate and timing of manure application. The erratic behavior of these treatments can be explained by the very important fact that once a soil becomes saturated, imposed manure treatments no longer play an important role on runoff. The quantity of runoff and sediment discharge becomes a function of the infiltration rate, percolation rate, slope, etc. for the various plots, or more broadly, for the heterogeneous soils within a watershed.

An intense rainstorm in August of 1972 (6.4 cm in one hour) was classified as excessive according to U.S. Weather Bureau standards with a probability of a 1 in 50 year occurrence. When this event occurred, the corn crop was at maximum height and nearly fully matured. With such a high intensity rainfall, one would expect severe erosion. Runoff and sediment losses of nitrogen and phosphorus were from 1 to 2 orders of magnitude lower than both the previous winters snowmelt event and the recent hurricane. The presence of an almost complete canopy of vegetative material over the soil surface was responsible for reducing rainfall impact, protecting the soil against erosion.

Early winter rainfall (3.8 cm in December) almost one year since the previous winter disposal and 8 and 7 months after the spring and summer applications resulted in approximately twice the discharge of these nutrients in runoff for the summer application, in comparison to winter and spring applications. The exposure of soluble nutrients on the soil surface (summer) versus the plowing down of manure (winter and spring) showed an influence at this later date.

Late winter rainfall for two selected runoff events (mid-March and early April 1973) served to illustrate the effects of residual nitrogen and phosphorus. The winter application for 1973 had already been applied. The second manure application cycle had not yet been applied to the spring and summer plots. Manure had been applied approximately 12 and 9 months prior to these two runoff events for the spring and summer application, respectively.

The discharge of nitrogen in surface runoff for winter applications was equivalent or less than the discharges from previous spring and summer applications. The residual nitrogen from prior applications was great enough to approximate the losses incurred from a very recent winter application. Nitrogen transformations from the organic to the inorganic fractions is occurring continuously and can supply an adequate amount of mobile inorganic nitrogen to runoff.

Phosphorus losses, on the other hand, displayed a higher discharge in surface runoff for the winter application because of readily available soluble phosphorus. The residual effects of phosphorus from the first cycle (spring and summer applications) was not as influential as nitrogen in supplying soluble material in runoff. Future availability of insoluble phosphorus from manure, like nitrogen, is provided by mineralization. Unlike inorganic nitrogen, soluble phosphorus is not highly mobile and soil fixation can render much of the soluble portion unavailable.

Sediment losses of nitrogen and phosphorus from these two runoff events were not significantly different with regard to the rate or timing of manure application.

A snowmelt event (December, 1973) accompanied by 1-2 cm of rainfall on non-frozen soil was selected to further study nutrient losses during the winter. On the whole, this runoff event accounted for only 5% of the annual runoff and 3% of the annual soil loss. Nutrient losses were inconsequential.

Runoff occurred two weeks prior to the beginning of the third winter's manure application. Average nitrogen and phosphorus losses for both runoff and sediment appeared to correlate to the lapsed time since manure disposal (summer > spring > winter). Nitrogen and phosphorus losses in runoff ranged from 0.03 to 1.2 kg/ha and 0.0 to 0.07 kg/ha, respectively. Sediment losses of these two nutrients were less than 0.07 kg/ha.

Runoff resulting from snowmelt and rainfall in February of 1974, one month after the third application to winter applied plots also resulted in minimal nutrient discharges. Losses in runoff and sediment did not exceed 0.5 and 0.15 kg/ha respectively, and were lowest for the winter applied plots. In general, residual losses of these two elements from the past spring and summer applications, contributed more to surface water and sediment discharges than a recent winter application. The 35 t/ha rates, regardless of the time of application, yielded essentially a zero discharge.

An intense rainstorm in June 1974 (4.6 cm in 75 minutes) occurred 12 days after the last summer application was applied on top of growing corn. The previous winter and spring applications had already been plowed down. Runoff and sediment losses were relatively low and compared to losses incurred during an intense storm in August 1972. Nitrogen in runoff and nitrogen and phosphorus in sediment did not exhibit a significant change relative to the rate and timing of manure application. Phosphorus showed a small but significant increase in runoff water for the summer application, owing to the very recent addition of manure.

The relationship between nutrient discharge and quantity of runoff water for these selected drainage events were almost non-existent. The data points contained considerable scatter because of varying soil surface conditions, which influences runoff, and a large amount of variability in nutrient concentrations, depending on the time of the year runoff occurred in relation to the lapsed time since manure disposal.

WINTER DISPOSAL

Accumulative nutrient losses from January to April for three consecutive (1972-1974) winter applications was studied. The main emphasis was placed on the rate of winter application and the variation in nutrient losses that can be expected from year to year. A comparison of several weather parameters was considered.

The winter of 1972 was fairly typical in terms of average precipitation where the winters of 1973 and 1974 were below normal. In addition, during the winter of 1972 there was a considerably greater number of days in which the soil was frozen (62 days) compared to 12 and 0 days for 1973 and 1974, respectively. Soil temperatures at 10 cm under sod was used as the criteria.

Nutrient losses of nitrogen and phosphorus as averaged over all rates of application was considerably greater in 1972 in comparison to the other years. Small differences existed between the winter of 1973 and 1974. Actual runoff values as averaged for the three rates of application for nitrogen was 16, 1 and 0.2 kg/ha for 1972, 1973 and 1974, respectively. Phosphorus values averaged 3.5, 0.7, and 0.01 kg/ha for the three respective years. Adverse weather conditions during and after the winter disposal in 1972 was largely responsible for increased discharges in runoff, especially at the 100 t/ha rate which was applied on top of dense melting snow, allowing for collection of data under extreme conditions.

The rate of application was extremely interesting over this three year winter period. Ignoring the 100 t/ha rate for the winter of 1972, because it was applied under conditions far removed from the 35 and 200 t/ha rates, the 200 t/ha rate resulted in approximately 4 times the nitrogen and phosphorus losses in runoff in comparison to 35 t/ha during 1972, but were essentially identical in 1973 and 1974. Even more interesting, the 35 t/ha rate applied in the winter across an array of weather patterns did not show any significant differences between the three years. Resultant nitrogen and phosphorus losses were less than 1.5 and 0.5 kg/ha respectively. With the exception of spreading on melting snow, nutrient loadings from the modest rate of 35 t/ha may well fall into the acceptable range when standards are established.

It was postulated that surface water loadings were greatest during 1972 because of the timing of a snow melt event, a more nearly normal amount of precipitation and a greater number of days when the soil was frozen. Sediment losses of nitrogen and phosphorus, however, were greatest during the winter of 1973. When dealing with sediment losses the condition of the soil surface is all important. With a given amount of precipitation, sediment yields would be greatest on an exposed surface as compared to an unexposed surface. The number of days of snow covered soil in 1972, 1973 and 1974 were 75, 39 and 64, respectively. In theory, soil protection from rainfall impact resulting from winter rains was lower in 1973, than in 1972 or 1974 because of less snow cover.

The greatest amount of sediment discharged in 1973, occurred from a single runoff event lasting 3 days as a result of precipitation, mostly in the form of rain. At the onset of runoff, the soil was without a cover of snow. The resultant sediment yield contributed greatly to the cumulative three months loss. Nutrient losses in sediment were not significantly different between the winters of 1972 and 1974.

NUTRIENT CONCENTRATIONS

Average nutrient concentrations and frequency distributions for nitrogen (NH_4-N, NO_3-N) and phosphorus (soluble inorganic and total soluble) in surface runoff and tile effluent were determined. Calculations of nitrogen and phosphorus concentrations and associated variability had been made for two complete manure application cycles (1972, 1973).

The most variable nutrient element in runoff was ammoniacal nitrogen. The greatest mean concentrations were associated with the winter 100 and 200 t/ha treatments (8.2 and 4.5 ppm, respectively). Three extremely high concentrations (100+ ppm) were responsible for the larger average concentrations. The three outlying observations all occurred from winter disposal as a result of a single snowmelt event of February 1972. With the exception of these two treatments, mean treatment concentrations were 1 ppm or less. Associated variability ranged from 100-475%.

Average nitrate-nitrogen concentrations in runoff displayed a smaller degree of variation between drainage events as compared to ammonium nitrogen. Mean concentrations ranged from 2.2 to 5.5 ppm with little reflection on treatment.

Frequency distributions of nitrogen in surface water effluent showed that approximately 80% of the frequency of ammonium nitrogen concentrations were less than 1.0 ppm and 90% of the frequency of nitrate nitrogen concentrations were less than 10 ppm.

Analytical determinations were made for both soluble inorganic and total soluble phosphorus, the numerical difference being composed of the soluble organic fraction. Like ammoniacal nitrogen, total soluble phosphorus exhibited the greatest mean concentrations for the 100 and 200 t/ha application rates (2.6 and 3.1 ppm respectively). Extreme concentrations, which markedly shifts the mean to higher levels, at the two higher rates of application, occurred during the winter of 1972 and were mainly associated with a single snow melt event in February. The average concentration of soluble phosphorus for the 35 t/ha winter treatment (0.9 ppm) was well in line with average concentrations for the various disposal rates for the spring and summer applications, which ranged from 0.3-1.1 ppm. Occurrences of concentrations less than 1.0 ppm were on the order of 80-90% of the time.

The concentration of these same forms of nitrogen and phosphorus had been determined in tile effluent on a weekly sampling basis. Only the 35 and 200 t/ha rates at each disposal period was studied. Mean concentrations of ammoniacal nitrogen were an order of magnitude lower in tile effluent in comparison to surface runoff. Mean concentrations for the various treatments ranged from 0.06 to 0.25 ppm. Concentrations of less than 0.1 ppm occurred nearly 85% of the time with little differences between the timing and rate of manure application.

Nitrate nitrogen, unlike ammoniacal nitrogen, moves readily with water through the soil profile. Mean nitrate nitrogen concentrations in the effluent ranged from 7 to 22 ppm and contained a high degree of variation between sampling periods. The lowest mean concentration was related to the plowing down of 35 t/ha in the spring. The frequency of nitrate nitrogen concentrations exceeding 10 ppm ranged from 45-70% of the time. The 200 t/ha rates, and the average effect of winter and summer disposal periods, approached the 70% level while the 35 t/ha rates and the average effect of the spring application accounted for the 45% frequency level.

Nearly 85% of the total soluble phosphorus in tile effluent is composed of the soluble inorganic fraction. Mean total soluble phosphorus concentration ranged from 0.01 - 0.1 ppm. Average concentrations for the winter and spring disposal periods were approximately 10 times greater at the higher rate of application, but little difference between rate of application was evident for the summer disposal period. Roughly 80% of the total soluble phosphorus concentrations as observed over all drainage events were less than 0.1 ppm.

RAINFALL SIMULATION

An irrigation experiment was initiated to study the movement of soluble nitrogen and phosphorus with time during a runoff event on a single plot that received 200 t/ha as a summer application. Nutrient concentrations in surface runoff did not vary greatly with the fluctuations in discharge water and a nearly constant concentration was maintained. Nutrient concentrations only began to drop at the cessation of runoff. The last 4 hours of flow was 'tail flow' in which laterally moving subsurface water, at a shallow depth, is being intercepted by the drainage ditch and diverted to the recording flume. Concentrations of nitrogen and phosphorus in the subsurface water were somewhat lower than in the water moving across the surface.

The discharge rates of inorganic nitrogen and total soluble phosphorus in runoff were calculated. Since the quantity of nutrients discharged is directly proportional to the flow and nutrient concentrations were relatively constant, a linear response was achieved between quantity of nutrients removed versus flow.

Similar calculations were made for tile effluent. Nitrate nitrogen concentrations were inversely related to flow while phosphorus concentrations were directly proportional to flow. Nitrate concentrations were considerably higher in tile effluent but lower in soluble phosphorus than surface water concentrations.

Nitrate discharge exhibited a poor linear relationship with flow. Phosphorus discharge displayed a quadratic response, not unexpectedly, since the highest concentrations were noted at peak flows.

SOIL RETENTION EFFICIENCY

The retaining efficiency of the soil for nitrogen and phosphorus was calculated on the basis of nutrient inputs from manure and the loss to the environment via runoff and sediment erosion. The inclusion of tile outflows were ignored because the 100 t/ha rate was not tile drained, making relative comparisons difficult.

The soil system in itself appeared to be an excellent disposal medium for dairy manure. The retaining efficiencies ranged from 89 to 99% for the imposed treatments for both nutrients. The lowest efficiency rating appeared for the winter applied 100 t/ha treatment. The reason for the lower retention was due primarily to the disposal of this treatment on dense melting snow in 1972.

SOIL ANALYSIS

Initial and terminal soil samples were obtained to determine the relationship between successive manure inputs and the increase in soil concentration of total nitrogen, available phosphorus and organic matter.

Increased rates of application, increased the concentration of these constituents in the soil as the result of three successive annual applications. In many cases, the 35 t/ha rate of application actually showed a negative response to manure additions. It was felt, however, that after a longer period of successive manure inputs, equilibrium will become established, and a positive increase will result.

A decay series for the mineralization of organic nitrogen from manure was calculated to determine the availability of nitrogen for plant growth and for potential nitrogen losses. A decay series of .55 - .30 - .16 was calculated. For a three year period, 55% of the organic nitrogen was mineralized from the first years input. The second year, 55% of the current input was mineralized plus 30% from the residual of the first year. After the third year, 55% was mineralized from the third years input, plus 30% of the residual from the second year, plus 16% of the residual from the first year. The total organic nitrogen input minus the sum of the organic nitrogen mineralized approximated the increase in soil organic nitrogen after three years.

CROP RESPONSE

Corn responded significantly to increasing rates of manure application. However, the efficiency of utilization of nitrogen by the corn crop dropped markedly as the rate of application increased. Once adequate supplies of nitrogen are provided, additional increments result in poor nitrogen conservation. Rates of manure application in the neighborhood of 35 t/ha combined with an experimentally determined rate of mineral fertilizer could result in optimum nitrogen conservation.

MANURE MANAGEMENT GUIDELINES

Due to extreme climatological variability within years as well as between years, nutrient losses become highly variable in themselves. Nevertheless, some very important principals have been observed and preliminary guidelines have been formulated. The guidelines discuss the watershed and dairy waste management aspects in relation to land application of manure and water quality.

COMPUTER SIMULATION FOR CONTROL LEGISLATION

A study of animal waste disposal legislation and its impact on dairy farms has been estimated with a mathematical computer simulation model. The model used was developed for the particular purpose of examining the effect of some hypothetical legislative controls designed to reduce pollution related to dairy manure disposal. A number of interesting observations can be seen from the results of the modeling procedures which have been presented.

1. The hypothetical controls which were studied exert their greatest influence over the dairy farms by way of reducing the acreage of land which is available for manure disposal. When this is coupled with low manure spreading rates, such as with Restriction Level 2, the controls simply prevent a herd size which is representative of today's dairy industry being reached without violating the restrictions.

2. At herd densities of less than 1.24 cows/ha (0.5 cows per acre), it appears possible to meet the requirements of limited manure disposal control, those of Restriction Level 1 without any significant reduction in farm income. Combined controls on manure spreading rates and fertilizer application rates have little effect on farm income where herd size is small, less than 0.25

cows/ha (0.1 cows/acre). These combined controls appear to reduce total losses of nutrients to surface and ground water at Restriction Level 2.

3. The greatest losses of nutrients to surface water appeared to be associated with soil erosion. Any change in management of the farm, brought about by restrictions on manure disposal, which results in and increase in soil loss will increase losses of nutrients to surface waters. This is especially true of changes brought about by a regulation which causes more land to be cultivated than before the regulation was enacted.

4. An increase in the area of cultivated land may result from legislation which requires that manure be disposed of only by utilization in a crop production program. This increase in cultivated land is most likely to occur on farms with poor soils. This means that the effect of a legislative control will be different on farms with soils of different suitability production. If legislative controls result in increases in cultivated land, there may be an increase in losses of nutrients to surface waters because of the soil loss factor discussed in (3) above. These same controls may, however, be effective in reducing losses of soluble nutrients in runoff and in water percolating to the ground water.

5. Increasing cow/land ratios increased the loss of nutrients to surface and groundwater from farms with poor soils in two ways; (a) by increasing the proportion of land cultivated for feed requirements; (b) by increasing the quantities of manure to be disposed of.

   On farms with productive soils, land which can be profitably cultivated will be cropped regardless of the size of the dairy herd, and most manure can be utilized in crop production. Thus cow/land ratios have little effect on losses from these farms unless large herd sizes are involved.

6. The effect of some controls on manure disposal is to prevent certain areas of land being used for manure disposal. At Restriction Level 2, this reduces the maximum cow/land ratio which can be attained, on New York farms used in this study, to a level of approximately .30-.32 cows/ha (0.12-0.13 cows/acre), far below usually suggested values for adequate manure disposal. The smaller the farm, the greater the proportion of the total area which is unavailable for manure disposal under these controls. If only those areas of the farm which can be used for manure spreading are considered, then the cow/land ratio is closer to 0.99 cows/

ha (0.4 cows/acre). Only by considering that land which is available for continuous corn production alone, could cow/land ratio be significantly increased above 0.99 cows/ha (0.4 cows/acre) at the high level of control of Restriction Level 2.

7. It is possible to meet the requirements of the controls by changing cropping practices. A shift from alfalfa to grass production for hay or hay-crop silage enables more land to be used for manure disposal. A reduction in corn acreages with a corresponding increase in the area of small grains makes for a more even distribution through the year of land areas on which manure may be spread. The availability of small grain stubble for manure spreading in the late summer is a reason for this change in cropping practices. The changes in cropping practice take place in spite of the lower income which the substituted crops bring to the farm.

SECTION VIII

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SECTION IX

GLOSSARY

Code of Practice - Guidelines suggested practical measures to be taken under a given set of circumstances. Usually compliance with the code of practice implies that an effort has been made to control a certain problem, and avoids punitive damages in subsequent lawsuits.

Constraint - In linear programming, a constraint is usually considered to be a set of conditions which must be equal to each other, or greater or less than some "right hand side" value. In this study, the term has also been used to describe hypothetical legislative controls which reduce the freedom of decision making enjoyed by a farmer with respect to his farm management decisions.

Conversion Table - FOR ENGLISH AND METRIC UNITS.

To convert col 1 to col 2 multiply by:	Column 1	Column 2	To convert col 2 to col 1 multiply by:
	Length		
0.621	Kilometer, km	Mile, mi	1.609
1.094	Meter, m	Yard, yd	0.914
0.394	Centimeter, cm	Inch, in.	2.540
	Area		
0.386	Kilometer^2, km	Mile^2, mi^2	2.590
2.471	Hectare, ha	Acre, acre	0.405

Conversion Table - (Cont'd.)

To convert col 1 to col 2 multiply by:	Column 1	Column 2	To convert col 2 to col 1 multiply by:
		Mass	
1.102	Ton (metric)	Ton (English)	0.9072
2.205	Kilogram, kg	Pound, lb	0.454
		Yield	
0.446	Ton (metric)/ hectare	Ton (English)/ acre	2.240
0.891	kg/ha	Lb/Acre	1.12
		Temperature	
(9/5 °C) + 32	Celsius, C	Fahrenheit, F	5/9(°F-32)

Denitrification - Microbial conversion of nitrate nitrogen to nitrogen or nitrogen oxide gasses. Carried out by soil organisms in an anaerobic environment.

Enrichment Ratio - The increase in the level of content of a substance in soil or water, brought about by a land use activity, over that which would occur if no activity, other than natural evolution, was to be imposed on the land.

Externality - External (dis)economy; an economic influence on the activities of another, with no connection or "feed back" to the economics of the activity causing the externality. Pollution is an external diseconomy when someone not connected to the pollution causing activity must suffer personal or economic loss as a result of the pollution, or must pay the cost of eliminating it with no recourse to those causing it.

Legislation - Legislative controls: a written statement enacted into law, the violation of which is an offense punishable under the law.

Manure - Animal excreta with or without added water or solid material, in a form suitable for spreading on the land.

a. Dumping - The practice of disposing of manure by applying very high application rates to an area of land on which no crop is grown.

b. Spreading - The practice of applying manure to a crop, or to land in preparation for a crop, with the intention of benefitting the crop as well as disposing of the manure.

c. Stockpiling - Holding or storing manure in above ground piles for spreading or dumping at a later date.

d. Treatment - Any practice which alters the chemical or physical nature of the manure, or both. Usually carried out in conjunction with a manure disposal program.

Mineralization - The microbial break-down of organic material from any source, with a consequent liberation of inorganic forms of the nutrients contained in the original organic material.

Net Revenue - The difference between the costs and the returns from the operation of the farm, excluding the value of labor supplied by the farmer and his immediate family and the costs of interest and taxes which must be paid on the land resources of the farm.

Optimization - Process of selecting the mix of activities, and the levels of these activities, which is optimum under the desired conditions - in this study that mix which gives the maximum net revenue to the farm operation.

Percolation - Seepage; the quantity of water which moves out of the soil, downwards or horizontally, and is not accounted for in runoff and evapotranspiration. Percolation or seepage nitrogen is that quantity of nitrogen which leaves the soil by this route.

Pollution - The addition of nutrients or other contaminants to the environment which results from the activities of man.

Sediment - The solid material which is carried from its place of origin by runoff water. Sediment nutrients are those nutrients contained in this sediment.

Selective Erosion Index - A measure of the physical and chemical processes which result in the sediment from erosion of a soil being higher in content of a nutrient, or other material, than the soil itself.

Shadow Prices - The marginal value product of a resource - the amount of change in the net revenue which would occur if a limited resource or constraint value was changed by one unit.

Volatilization - The loss of an element by transfer from the soluble state to the vapor state -- specifically the loss of ammonia nitrogen by this mechanism brought out by drying, high pH or freezing.

SECTION X

APPENDIX

Table A1. ANNUAL DISCHARGE OF WATER, INORGANIC NITROGEN AND SOLUBLE PHOSPHORUS IN SURFACE RUNOFF FOR INDIVIDUAL PLOTS, 1972.

Soil mg't	Time of applic	Rate, t/ha	Runoff, cm	Inorganic-N, kg/ha	Total solu-P, kg/ha	Plot no.
Poor	Winter	35	14.1	6.41	0.988	4,15
		100	35.5	90.73	15.021	18
		200	13.4	14.13	5.208	6
	Spring	35	14.6	5.01	0.317	5,22
		100	28.3	5.18	0.736	13
		200	19.2	5.79	1.506	1
	Summer	35	7.9	3.10	0.263	8,16
		100	62.3	25.60	3.564	17
		200	50.2	19.96	4.239	3
Good	Winter	35	6.5	4.25	0.335	21,24
		100	9.6	35.61	5.319	19
		200	6.0	6.39	2.341	11
	Spring	35	6.6	2.67	0.121	2,9
		100	17.0	17.07	0.276	10
		200	11.4	18.50	7.184	7
	Summer	35	20.7	17.17	2.124	12,20
		100	23.4	7.08	0.902	14
		200	2.6	1.77	0.256	23

Table A2. ANNUAL DISCHARGE OF WATER, INORGANIC NITROGEN AND SOLUBLE PHOSPHORUS IN SURFACE RUNOFF FOR INDIVIDUAL PLOTS, 1973.

Soil mg't	Time of applic	Rate, t/ha	Runoff, cm	Inorganic-N, kg/ha	Total solu-P, kg/ha	Plot no.
Poor	Winter	35	5.56	0.59	0.37	4,15
		100	11.86	4.11	3.14	18
		200	2.99	0.54	1.93	6
	Spring	35	5.31	0.76	0.08	5,22
		100	11.23	3.79	0.15	13
		200	7.47	1.94	0.24	1
	Summer	35	1.85	0.41	0.12	8,16
		100	17.98	4.74	0.59	17
		200	17.14	4.56	0.60	3
Good	Winter	35	2.51	1.62	0.45	21,24
		100	2.21	1.67	0.42	19
		200	2.21	0.86	0.91	11
	Spring	35	2.44	0.49	0.02	2,9
		100	4.95	1.29	0.05	10
		200	1.96	0.54	1.36	7
	Summer	35	5.08	1.63	0.17	12,20
		100	6.02	1.62	0.10	14
		200	0.30	0.11	0.02	23

Table A3. ANNUAL DISCHARGE OF INORGANIC NITROGEN AND TOTAL SOLUBLE PHOSPHORUS IN SURFACE RUNOFF FOR GIVEN TREATMENTS. 1972, 1973.

Treatment	N, kg/ha			P, kg/ha			Runoff, cm		
	1972	1973	Ave.	1972	1973	Ave.	1972	1973	Ave.
Time									
Winter	21.1a	1.5a	11.3a	3.8a	1.0a	2.4a	13.2a	4.3a	8.9
Spring	7.7b	1.2a	4.4a	1.3b	0.2b	0.8a	14.7a	5.1a	9.9
Summer	11.9c	1.9a	6.9a	1.7b	0.2b	1.0a	24.4b	6.6a	15.5
Rate, mt/ha									
35	6.4a	0.9a	3.6a	0.7a	0.2a	0.4a	11.7a	3.8a	7.8
100	30.2b	2.9b	16.5b	4.3b	0.8b	2.6a	29.5b	9.1b	19.3
200	11.1c	1.5a	6.3ab	3.5c	0.9b	2.2a	17.3c	5.1a	11.2
Soil mg't									
Good	11.2a	1.1a	6.2a	1.8a	0.3a	1.0a	11.4a	3.0a	7.2
Poor	15.8b	1.9a	8.8a	2.8b	0.7b	1.8a	23.6b	7.6b	15.6
Overall Means	13.6a	1.6b	7.6	2.2a	0.5b	1.4	17.5a	5.3b	11.4

[a] Means followed by the same letters are not significantly different @ 5% level in the verticle column and for row values in the overall means.

Table A4. ANNUAL DISCHARGE OF SOIL, TOTAL NITROGEN, TOTAL PHOSPHORUS AND ORGANIC MATTER IN SEDIMENT FOR INDIVIDUAL PLOTS, 1972.

Soil mg't	Time of applic	Rate, t/ha	Soil loss, t/ha	Total-N, kg/ha	Total-P, kg/ha	Organic matter, kg/ha	Plot no.
Poor	Winter	35	1.767	6.2	2.59	107	4,15
		100	4.649	26.6	9.97	614	18
		200	3.361	17.3	6.27	316	6
	Spring	35	0.901	3.7	1.42	65	5,22
		100	1.867	8.7	3.22	155	13
		200	15.751	48.0	20.26	970	1
	Summer	35	.485	1.7	0.68	28	8,16
		100	5.870	25.3	11.21	324	17
		200	4.023	15.7	6.82	313	3
Good	Winter	35	0.373	1.2	0.45	25	21,24
		100	2.054	9.8	3.17	277	19
		200	0.318	1.6	0.66	30	11
	Spring	35	0.539	2.2	0.66	41	2,9
		100	0.452	1.8	0.61	35	10
		200	2.211	13.8	4.34	244	7
	Summer	35	0.369	1.5	0.60	29	12,20
		100	0.368	1.5	0.59	27	14
		200	0.020	0.2	0.04	2	23

Table A5. ANNUAL DISCHARGE OF SOIL, TOTAL NITROGEN, TOTAL PHOSPHORUS AND ORGANIC MATTER IN SEDIMENT FOR INDIVIDUAL PLOTS, 1973.

Soil mg't	Time of applic	Rate, t/ha	Soil loss, t/ha	Total-N, kg/ha	Total-P, kg/ha	Organic matter, kg/ha	Plot No.
Poor	Winter	35	1.44	6.2	2.7	130.5	4,15
		100	2.60	17.0	6.9	305.6	18
		200	0.31	2.6	1.1	55.8	6
	Spring	35	1.42	7.1	3.2	128.8	5,22
		100	2.83	11.6	4.9	253.1	13
		200	4.76	15.5	6.7	357.6	1
	Summer	35	0.96	3.9	1.7	72.0	8,16
		100	1.31	6.2	3.1	95.0	17
		200	0.88	3.4	1.5	75.7	3
Good	Winter	35	0.19	0.8	0.4	16.1	21,24
		100	0.28	1.8	0.8	32.8	19
		200	0.53	3.9	1.8	83.5	11
	Spring	35	0.35	1.5	0.6	31.7	2,9
		100	0.66	2.6	1.1	54.1	10
		200	0.79	3.5	1.7	60.0	7
	Summer	35	0.81	3.8	1.6	94.0	12,20
		100	1.99	10.6	4.5	194.8	14
		200	0.01	0.1	0.03	1.1	23

Table A6. ANNUAL DISCHARGE OF SOIL, TOTAL NITROGEN, TOTAL PHOSPHORUS AND ORGANIC MATTER IN SEDIMENT FOR GIVEN TREATMENTS. 1972, 1973

Treatment	Total-N, kg/ha			Total-P, kg/ha			Org. mat., kg/ha			Soil loss, kg/ha		
	1972	1973	Ave.	1972	1973	Ave.	1972	1973	Ave.	1972	1973	Ave.
Time												
Winter	8.7 ab	4.9 a	6.8	3.2 ab	2.1 a	2.6	188 a	96 a	192	1832 a	875 a	1354
Spring	10.6 b	6.3 a	8.4	4.1 b	2.8 a	3.4	202 a	131 a	166	2894 a	1582 b	2238
Summer	6.1 a	4.4 a	5.2	2.6 a	2.0 a	2.3	97 b	109 a	103	1497 a	965 a	1231
Rate, mt/ha												
35	2.7 a	3.9 a	3.3	1.1 a	1.7 a	1.4	49 a	78 a	64	739 a	862 a	800
100	12.3 b	8.3 b	10.3	4.8 b	3.5 b	4.2	237 b	156 b	196	1542 b	1624 b	2083
200	16.2 c	4.8 a	10.5	6.4 c	2.2 a	4.3	312 c	105 a	208	4280 c	1215 ab	2748
Soil mg't												
Good	3.2 a	2.9 a	3.0	1.1 a	1.3 a	1.2	67 a	59 a	63	665 a	579 a	622
Poor	13.8 b	7.5 b	10.6	5.6 b	3.3 b	4.4	256 b	150 b	203	3485 b	1702 b	2593
Overall Mean	8.5 a	5.2 b	6.8	3.3 a	2.3 a	2.8	162 a	105 b	134	2075 a	1141 b	1608

[a] Means followed by the same letter are not significantly different @ 5% level in the verticle column and for the row values in the overall means.

Table A7. DAIRY MANURE COMPOSITION, 1972.

Time	Dry matter, %	NH_4-N, %	Total-N, %	Inorganic-P, %	Total solu-P, %	Total-P, %
Winter						
mean	23.25	0.51	1.90	0.16	0.21	0.47
std dev	6.10	0.37	0.74	0.11	0.11	0.19
range	13.0-39.8	0.12-1.61	0.99-3.66	0.04-0.45	0.07-0.47	0.16-1.03
Spring						
mean	10.14	0.74	2.80	0.19	0.34	0.51
std dev	3.41	0.27	0.64	0.10	0.15	0.10
range	15.0-33.0	0.14-1.28	1.11-4.02	0.02-0.39	0.04-0.64	0.28-0.70
Summer						
mean	19.48	0.84	2.80	0.14	0.31	0.55
std dev	2.38	0.18	0.50	0.11	0.10	0.10
range	16.0-27.0	0.43-1.20	1.83-4.63	0.01-0.38	0.01-0.52	0.38-0.81
Combined						
mean	20.99	0.67	2.41	0.16	0.28	0.51
std dev	4.54	0.30	0.65	0.11	0.12	0.14
range	13.0-39.8	0.12-1.61	0.99-4.63	0.01-0.45	0.01-0.64	0.16-1.03

Table A8. DAIRY MANURE COMPOSITION, 1973.

Time	Dry matter, %	NH_4-N, %	Total-N, %	Inorganic-P, %	Total solu-P, %	Total-P, %
Winter						
Mean	23.62	0.340	2.175	0.192	0.301	0.514
Std Dev	1.29	0.173	0.809	0.116	0.168	0.162
Range	14.0 - 38.0	0.11 - 0.66	0.68 - 3.80	0.04 - 0.45	0.05 - 0.58	0.28 - 0.87
Spring						
Mean	19.17	0.168	2.569	0.380	0.401	0.645
Std Dev	2.37	0.029	0.389	0.069	0.080	0.079
Range	16.0 - 27.0	0.11 - 0.22	1.90 - 3.32	0.23 - 0.49	0.24 - 0.50	0.46 - 0.80
Summer						
Mean	24.65	0.140	2.296	0.310	0.333	0.679
Std Dev	5.34	0.044	0.674	0.135	0.140	0.170
Range	17.3 - 38.0	0.07 - 0.23	1.30 - 3.70	0.12 - 0.55	0.14 - 0.58	0.49 - 1.10
Combined						
Mean	22.48	0.216	2.341	0.294	0.345	0.614
Std Dev	5.59	0.136	0.679	0.134	0.139	0.159
Range	14.0 - 38.0	0.07 - 0.66	0.68 - 3.80	0.04 - 0.55	0.05 - 0.58	0.28 - 1.10

Table A9. TOTAL NUTRIENT INPUTS FROM DAIRY MANURE, 1972

Soil mg't	Time of applic	Rate, t/ha	Dry matter, kg/ha	NH_4-N, kg/ha	Total-N, kg/ha	Total-P, kg/ha	Plot no.
Poor	Winter	35	8548	20	153	40	4,15
		100	24621	139	455	129	18
		200	47418	241	767	129	6
	Spring	35	6448	58	202	34	5,22
		100	18052	144	533	95	13
		200	43260	280	1012	208	1
	Summer	35	5657	57	169	37	8,16
		100	19008	179	563	112	17
		200	43347	353	1106	236	3
Good	Winter	35	9448	26	128	38	21,24
		100	19281	136	447	88	19
		200	51056	188	778	224	11
	Spring	35	5948	52	184	34	2,9
		100	17253	143	578	96	10
		200	40894	174	868	164	7
	Summer	35	5980	52	194	36	12,20
		100	19148	128	525	110	14
		200	46345	315	1034	197	23

Table A10. TOTAL NUTRIENT INPUTS FROM DAIRY MANURE, 1973.

Soil mg't	Time of applic	Rate, t/ha	Dry matter, kg/ha	NH_4-N, kg/ha	Total-N, kg/ha	Total-P, kg/ha	Plot no.
Poor	Winter	35	10967	26	158	50	4,15
		100	28286	55	460	129	18
		200	42134	129	898	215	6
	Spring	35	7037	11	169	47	5,22
		100	18957	31	439	124	13
		200	40484	60	995	259	1
	Summer	35	6980	11	181	57	8,16
		100	23275	29	550	157	17
		200	57562	68	1127	340	3
Good	Winter	35	5682	31	176	42	21,24
		100	30558	58	370	95	19
		200	46927	144	819	208	11
	Spring	35	5186	11	164	42	2,9
		100	19470	39	572	121	10
		200	38203	62	828	235	7
	Summer	35	5902	11	167	52	12,20
		100	30930	18	511	148	14
		200	50178	65	1082	316	23

Table All. AVERAGE SURFACE RUNOFF (R) AND SOIL LOSS (SL) FOR SELECTED RUNOFF EVENTS.

Date	2/29/72		6/26/72		8/27/72		12/7/72		3/19/73		4/6/73	
Treatment	R cm	SL kg/ha	R cm	SL kg/ha	R cm	SL kg/ha	R cm	SL kg/ha	R cm	SL kg/ha	R cm	SL kg/ha
35 mt/ha												
Winter	.88	5.9	3.71	583.1	.81	188.3	.61	16.4	2.37	763.3	1.20	41.8
Spring	1.11	33.8	3.43	321.5	.60	197.7	.32	15.7	1.58	677.2	1.55	150.8
Summer	3.32	50.1	5.84	96.7	.79	140.2	.53	4.5	2.06	842.5	1.25	41.9
100 mt/ha												
Winter	4.06	276.7	5.64	1178.7	1.07	352.7	1.40	-[a]	3.12	1064.0	1.98	122.0
Spring	1.66	11.2	7.72	379.5	.70	139.8	1.26	40.0	3.30	1093.6	2.82	358.5
Summer	3.75	26.6	11.61	546.4	.77	203.5	2.24	29.0	2.90	830.0	4.00	580.6
200 mt/ha												
Winter	1.32	25.9	3.30	1324.0	.46	84.22	.83	3.0	1.13	327.3	1.19	82.9
Spring	3.90	670.1	4.72	6997.4	.89	233.3	.51	85.0	2.53	2455.9	1.32	212.5
Summer	3.76	4.5	7.26	547.9	.81	109.0	1.66	6.6	1.52	272.8	4.17	113.8

[a] Unavailable due to small sample size.

Table A11 (Continued). AVERAGE SURFACE RUNOFF (R) AND SOIL LOSS (SL) FOR SELECTED RUNOFF EVENTS.

Date	12/27/73		2/24/74		6/11/74	
Treatment	R cm	SL kg/ha	R cm	SL kg/ha	R cm	SL kg/ha
35 mt/ha						
Winter	.10	.78	.01	.20	.27	146.2
Spring	.10	.78	.06	1.42	.25	58.2
Summer	-	-	.07	-	.22	70.9
100 mt/ha						
Winter	.44	4.7	-	-	.09	24.2
Spring	.33	5.5	.30	13.6	.38	90.8
Summer	1.36	8.5	.51	25.1	.19	5.6
200 mt/ha						
Winter	.03	.2	.09	6.6	.15	72.7
Spring	.09	3.1	.10	30.6	.28	322.8
Summer	.36	12.2	.37	9.30	.09	4.2

Table A12. AVERAGE CONCENTRATIONS OF INORGANIC NITROGEN IN SURFACE RUNOFF FOR SELECTED RUNOFF EVENTS. VALUES EXPRESSED IN ppm.

Date	2/29/72		6/26/72		8/27/72		12/7/73		3/19/73		4/6/73	
Treatment	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N
35 mt/ha												
Winter	11.0	.05	.09	8.34	.06	.88	.07	.79	.39	5.49	.17	1.70
Spring	.36	.84	.10	8.29	.06	.69	.07	1.53	.12	.73	.07	2.05
Summer	6.99	.24	.13	7.51	.07	.73	.06	2.01	.20	2.36	.06	2.54
100 mt/ha												
Winter	113.0	.73	.11	10.5	.08	.78	.05	1.98	1.31	3.59	.49	2.53
Spring	.44	1.16	.10	8.95	.06	.78	.07	2.08	.08	1.45	.07	2.32
Summer	.54	.95	.35	3.38	.10	.80	.08	3.22	.09	.79	.07	2.26
200 mt/ha												
Winter	83.75	.95	.11	3.7	.05	.78	.02	1.44	1.06	1.23	.31	2.68
Spring	11.44	.43	.23	4.52	.05	.69	.08	2.30	1.15	.80	.12	2.96
Summer	.27	.82	.90	8.35	.12	1.94	.04	2.78	.13	2.62	.06	2.19

Table A12 (Continued). AVERAGE CONCENTRATIONS OF INORGANIC NITROGEN IN SURFACE RUNOFF FOR SELECTED RUNOFF EVENTS. VALUES EXPRESSED IN ppm.

Date	12/27/73		2/24/74		6/11/74	
Treatment	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N
35 mt/ha						
Winter	.08	3.33	.13	4.49	.20	2.26
Spring	.06	2.73	.61	2.26	.25	4.80
Summer	-[a]	-	1.02	3.30	1.90	.52
100 mt/ha						
Winter	.12	6.5	-	-	.13	3.50
Spring	.11	25.62	.17	9.56	.54	5.50
Summer	.11	10.00	.24	6.43	4.99	.03
200 mt/ha						
Winter	.15	19.15	.29	5.15	1.03	3.75
Spring	.08	.38	.15	26.50	.28	3.63
Summer	.17	30.00	.31	8.75	9.74	11.25

[a] No flow recorded.

Table A13. AVERAGE INORGANIC PHOSPHORUS (SIP) AND TOTAL SOLUBLE PHOSPHORUS (TSP) IN SURFACE RUNOFF FOR SELECTED RUNOFF EVENT. VALUES EXPRESSED IN ppm.

Date	2/29/72		6/26/72		8/27/72		12/7/72		3/19/73		4/6/73	
Treatment	SIP	TSP	SIP	TSP	SIP	TSP	SIP	TSP	SIP	TSP	SIP	TSP
35 mt/ha												
Winter	2.98	4.08	.11	.20	.23	.32	.16	.34	1.12	1.41	.74	.85
Spring	.10	.11	.10	.14	.09	.12	.22	.31	.09	.14	.07	.09
Summer	1.19	1.62	.29	.48	.19	.21	.21	.29	.50	.67	.13	.17
100 mt/ha												
Winter	21.65	22.55	.18	.21	.27	.34	.12	.17	2.00	2.55	1.90	2.04
Spring	.06	.06	.18	.28	.04	.09	.18	.31	.09	.13	.07	.09
Summer	.11	.12	.87	1.03	.29	.45	.46	.59	.13	.18	.17	.20
200 mt/ha												
Winter	33.82	34.80	.23	.35	.17	.19	.21	.29	3.89	7.20	3.35	3.42
Spring	3.55	4.45	.46	.62	.12	.14	.59	.72	3.02	4.07	.39	.41
Summer	.05	.06	1.46	1.71	1.05	1.15	.67	.79	.40	.55	.32	.34

Table A13 (Continued). AVERAGE INORGANIC PHOSPHORUS (SIP) AND TOTAL SOLUBLE PHOSPHORUS (TSP) IN SURFACE RUNOFF FOR SELECTED RUNOFF EVENTS. VALUES EXPRESSED IN ppm.

Date	12/27/73		2/24/74		6/11/74	
Treatment	SIP	TSP	SIP	TSP	SIP	TSP
35 mt/ha						
Winter	.06	.10	.64	.71	.19	.23
Spring	.04	.07	.06	.08	.13	.15
Summer	-[a]	-	.26	.29	1.27	1.52
100 mt/ha						
Winter	.12	.14	-	-	.37	.37
Spring	.11	.15	.07	.08	.16	.17
Summer	.57	.58	.38	.39	1.66	2.68
200 mt/ha						
Winter	.20	.28	.38	.46	.53	.58
Spring	.52	.57	.21	.27	.29	.32
Summer	1.34	1.46	.31	.39	5.20	8.34

[a] No flow recorded.

Table A14. AVERAGE TOTAL NITROGEN (TOT-N) AND TOTAL PHOSPHORUS (TOT-P) IN SEDIMENT FOR SELECTED RUNOFF EVENTS. VALUES EXPRESSED IN PERCENT.

Date	2/29/72		6/26/72		8/27/72		12/7/72		3/19/73		4/6/73	
Treatment	Tot-N	Tot-P	Tot-N	Tot-P	Tot-N	Tot-P	Tot-N	Tot-N	Tot-N	Tot-P	Tot-N	Tot-P
35 mt/ha												
Winter	.84	.43	.36	.14	.36	.14	.34	.21	.44	.19	.48	.23
Spring	.40	.14	.42	.16	.40	.14	.43	.20	.44	.20	.44	.17
Summer	.59	.25	.68	.17	.36	.15	.39	.20	.45	.19	.43	.16
100 mt/ha												
Winter	.72	.26	.42	.15	.39	.17	.47	.22	.67	.27	.58	.26
Spring	-[a]	-	.46	.14	.42	.13	.39	.18	.38	.16	.42	.17
Summer	.38	.15	.44	.19	.38	.16	.50	.31	.49	.22	.35	.23
200 mt/ha												
Winter	.84	.33	.49	.18	.46	.16	.40	.27	.90	.39	.68	.42
Spring	.56	.18	.38	.16	.36	.14	.45	.25	.39	.18	.35	.16
Summer	.85	.19	.52	.19	.52	.19	.46	.22	.45	.21	.42	.20

[a] Unavailable due to small sample size.

Table A14 (Continued). AVERAGE TOTAL NITROGEN (TOT-N) AND TOTAL PHOSPHORUS (TOT-P) IN SEDIMENT FOR SELECTED RUNOFF EVENTS. VALUES EXPRESSED IN PERCENT.

Date	12/27/73		2/24/74		6/11/74	
Treatment	Tot-N	Tot-P	Tot-N	Tot-P	Tot-N	Tot-P
35 mt/ha						
Winter	.56	.18	.56	.18	.35	.17
Spring	.68	.20	.68	.20	.34	.16
Summer	-	-	-	-	.30	.16
100 mt/ha						
Winter	-	-	-	-	.45	.22
Spring	.61	.16	.61	.16	.40	.16
Summer	.64	.27	.64	.27	.80	.49
200 mt/ha						
Winter	.74	.27	-	-	.44	.22
Spring	.44	.12	.44	.12	.40	.16
Summer	.60	.21	.60	.21	.90	.94